DOCUMENT RESUME

ED 092 328 SE 016 383

AUTHOR	De Kock, Walter Eugene
TITLE	An Analysis of Student Performance Using a Laboratory Oriented High School Physics Program.
PUB DATE	72
NOTE	282p.; Ph.D. Dissertation, Ohio State University
AVAILABLE FROM	University Microfilms, 300 North Zeeb Road, Ann Arbor, Michigan 48106 (Order No. 73-11,482, Microfilm-$5.00, Xerography-$11.00)
EDRS PRICE	MF-$0.75 HC-$13.80 PLUS POSTAGE
DESCRIPTORS	Doctoral Theses; *Educational Research; Learning; *Mechanics (Physics); Personality Assessment; *Physics; Science Education; *Secondary School Science
IDENTIFIERS	Physical Science Study Committee; *Research Reports; Wave Motion

ABSTRACT

This study was designed to assess the use of an individualized laboratory-oriented high school physics program used in one Black Hawk County, Iowa, school. The three problems investigated were: (1) what short-term and long-term learning resulted from the use of the materials, (2) what student characteristics were related to learning outcomes, and (3) what characteristics of the materials were related to learning outcomes? Data were collected on 48 students and involved general intelligence; sex; IOWA TESTS OF EDUCATIONAL DEVELOPMENT scores on the BACKGROUND IN THE NATURAL SCIENCES TEST, READING IN THE NATURAL SCIENCE TEST, QUANTITATIVE THINKING TEST and the Composite score; personality types as determined by the MYERS-BRIGGS TYPE INDICATOR; score on selected PSSC test items; scores on Part, unit and final tests constructed to evaluate understanding of concepts found in the materials; and rate of completion. Concepts in the areas of mechanics and wage motion were emphasized in the physics materials, with the processes of science being an integral part of the materials. Data analyses revealed that individual personality types showed no consistency in correlating significantly with program test scores or rate of progress; the sample was scholastically inclined when described by scores on the Iowa tests; the more able students achieved greater success with the materials than did the less able. (Author/PEB)

AN ANALYSIS OF STUDENT PERFORMANCE USING A LABORATORY ORIENTED HIGH SCHOOL PHYSICS PROGRAM

DISSERTATION

Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

By

Walter Eugene De Kock, B.A.,M.A.Ed.

* * * * *

The Ohio State University
1972

Approved by

Adviser
College of Education

U S DEPARTMENT OF HEALTH
EDUCATION & WELFARE
NATIONAL INSTITUTE OF
EDUCATION
THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL NATIONAL INSTITUTE OF EDUCATION POSITION OR POLICY

ED 092528

AN ANALYSIS OF STUDENT PERFORMANCE USING A LABORATORY ORIENTED HIGH SCHOOL PHYSICS PROGRAM

by

Walter Eugene De Kock, Ph.D.

The Ohio State University, 1972

Professor Robert W. Howe, Adviser

The general problem of this study was to assess the use of an individualized laboratory oriented high school physics program used in one Black Hawk County, Iowa school. The specific problems were:

1. What short-term and long-term learning result from use of the materials?
2. What student characteristics are related to learning outcomes?
3. What characteristics of the materials are related to learning outcomes?

The three aspects on which data on the forty-eight students in the sample were collected were those concerning personal characteristics of the learner, the level of educational development of the learner, and performance on physics test items. Data utilized were general intelligence; sex; Iowa Tests of Educational Development scores on the Background in the Natural Sciences Test, Reading in the Natural Sciences Test, Quantitative Thinking Test and the Composite score; behavior types as determined by the Myers-Briggs Type Indicator; score on selected PSSC test items; the scores on Part, unit, and final tests

SE 016 383

constructed to evaluate understanding of concepts found in the materials; and rate of completion.

Concepts in two broad areas, mechanics and wave motion, were found emphasized in the materials. Processes of science were an integral part of the materials and received major emphasis throughout.

Analysis of the characteristics of the sample resulted in the conclusion that intelligence was not a significant factor in determining who enrolled as 38 percent of the sample were found at or below the senior class mean of 112. Little difference in preference for behavior between extraversion or introversion and thinking or feeling was found. Intuition was preferred over sensing, 75 percent to 25 percent, and perception was preferred over judgement, 79 percent to 21 percent. Individual types showed no consistency in correlating significantly with program test scores or rate of progress. The sample was composed of 7 girls and 41 boys. This was approximately 11 percent and below the national average for girls enrolling in physics. Iowa Tests of Educational Development scores, based on Iowa norms exhibited a distribution over almost the whole percentile range but averaged 67 to 80. The sample was scholastically inclined.

Unit I Test and Unit II Test Scores and the Equated Final Test Score were best predicted by ITED Quantitative Thinking standard scores with variances of 33.19, 41.56 and 44.02 percent respectively computed by multiple regression. The program was judged to contain substantial emphasis on mathematical models--sentence models, graph models, and data table models.

More able students achieved greater success with the materials. Intelligence quotients correlated significantly in a positive direction with the Unit I Test Scores at the .05 level, with the Unit II Test Scores at the .001 level; and with the Equated Final Test Score at the .01 level. Intelligence quotients correlated positively at the .01 level of significance with the total number of materials Parts completed during the school year.

The behavior types as determined by use of the Myers-Briggs Type Indicator provided little significant data. Consistency in results were not found.

Analysis of concepts in test items, test item type, test item correlations, analysis of item relationships and average cluster item difficulty were used to determine if learning hierarchies existed. Learning hierarchies were found for translational and rotational motion, velocity and falling bodies, force, acceleration, and oscillation. However, the learning hierarchies were not sequentially developed from subordinate to terminal behavior. Many of the items in the hierarchies were of a quantitative nature. These data strongly indicate the need for program revision.

Data is given on the reliabilities of the instruments, recommendations are made for changes in the program materials, and suggestions are made for further research.

ACKNOWLEDGMENTS

The writer gratefully acknowledges his appreciation to those individuals who have made this study possible.

The administration of the University of Northern Iowa and Iowa State Board of Regents provided a Professional Development Leave for one semester.

The administration at Columbus High School and The Malcolm Price Laboratory School most graciously sanctioned the study and provided confidential information.

Mr. Walter Gohman and Mr. Wayne Wessels cooperated faithfully in teaching the program and administering the instruments used in the study.

The encouragement, guidance, scholarsnip, leadership and understanding of my adviser, Dr. Robert V. Howe, have been a constant inspiration.

The advice and suggestions of Dr. William R. Riley and Dr. Stanley L. Helgeson were very helpful. Their critical reading of the entire manuscript was sincerely appreciated.

To my wife, Joyce, and our children Walter John, Cynthia, Elaine, Joel, and Wayne is extended a special acknowledgment. Their encouragement, patience, understanding, and willing cooperation have made the completion of the doctoral program possible.

VITA

1929	Born, Grand Haven, Michigan
1951	B.A. Central College, Pella, Iowa
1951-52	Junior High Teacher, Griswold Consolidated School, Griswold, Iowa
1952-53	Elementary Science and Health Teacher, Newton Community Schools, Newton, Iowa
1953-54	M.A.Ed., University of Northern Iowa, Cedar Falls, Iowa
1954-55	Assistant Principal and Elementary Science and Health Teacher, Newton Community Schools, Newton, Iowa
1955-56	Instructor, Wayne State University, Detroit, Michigan
1956-57	Director of Elementary Education, Emmetsburg Community Schools, Emmetsburg, Iowa
1957-64	Educational Consultant, Linn County Schools, Cedar Rapids, Iowa
1964-72	Assistant Professor of Science Education, University of Northern Iowa, Cedar Falls, Iowa
1961-72	Student, The Ohio State University, Columbus, Ohio

FIELDS OF STUDY

Studies in Science Education, Professor John S. Richardson

Studies in Secondary Education, Professor Jack R. Frymier

Studies in Biology, Professor Clarence E. Taft

TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS iii

VITA iv

LIST OF TABLES viii

Chapter

I. INTRODUCTION 1

The Problem
Need for the Study
Physics Enrollments
Problem and Sub-Problems, and Hypotheses
   Hypotheses concerning short and long-term learning
   Hypotheses concerning students
   Hypotheses concerning materials
Definitions
Delimitations of the Study
Limitations of the Study
Assumptions
   Assumptions of the program assessed
   Assumptions of the investigator
Overview of the Study
   Summary and overview of chapters to follow

II. REVIEW OF RELATED LITERATURE 15

Physics Enrollments
Psychological Factors
   Motivation
   Self-paced learning
   Structure of learning
   Hierarchy based learning materials
   Personality factors

TABLE OF CONTENTS (Contd.)

Chapter Page

III. DESIGN OF THE STUDY 31

Selection of Sample School and Sample Teacher
Analysis of Content of Materials
Selection and Evaluation of Instruments
  Selected evaluation instruments utilized by the school on a regular basis
  Special evaluation instruments selected with previous use
  Evaluation instruments developed by the investigator
Collection of Data
  Procedures
  Timetable of study
Analysis of Data
Summary

IV. THE FINDINGS 45

Introduction
Concepts and Processes
  Concepts included in the materials
  Processes of science utilized in the materials
  Summary
Characteristics of the Sample
  Preference for Myers-Briggs Type
  Intelligence quotients
  Iowa Tests of Educational Development
  Sex
  Summary
Performance Characteristics
  Scores on Unit I Test
  Scores on Unit II Test
  Scores on Unit III or IV Tests
  Part Score
  Final Test Score
  Equated Final Test Score
  Equated PSSC Score
  Summary
Learning Hierarchies
  Concepts in test items and their selection
  The test item type
  Correlation of test items
  Analysis of item relationships
  Determining average cluster item difficulty
  Interpreting cluster relationships
  Established hierarchies and analysis
  Summary

TABLE OF CONTENTS (Contd.)

Chapter Page

Analysis of Hypotheses
  Hypotheses concerning short and long-term learning
  Hypotheses concerning students
  Hypotheses concerning materials
  Summary

V. SUMMARY, CONCLUSION, AND RECOMMENDATIONS 91

Restatement of Problem
Major Findings
  Concepts and processes
  Characteristics of the sample
  Predicting success with materials
  Learning hierarchies
  Short and long-term learning
  Student characteristics related to learning
  Materials characteristics related to learning
Recommendations for Changes in the Materials
Recommendations for Further Research

Appendix

A. Concepts: Scope and Sequence 103

B. Processes: Description and Listing 126

C. Characteristics Form Sample 258

D. Achievement Report Form 260

SELECTED REFERENCES 262

LIST OF TABLES

Table Page

1. Funneling of Test Items to Final Test 38
2. Variance: Columbus 1970-71 with Columbus 1969-70 43
3. Percentage of Columbus Sample Found in Sixteen Type Groups and Individual Types 49
4. Sample Characteristics 1969-70 51
5. Summation of Sample Characteristics 53
6. Multiple Regression with Score on Unit I Test as Dependent Variable 56
7. Multiple Regression with Score on Unit II Test as Dependent Variable 57
8. Multiple Regression with Part Score as Dependent Variable 58
9. Multiple Regression with Final Test Score as Dependent Variable 59
10. Multiple Regression with Equated Final Test Score as Dependent Variable 60
11. Multiple Regression with Equated PSSC Score as Dependent Variable 61
12. Variables Related to Success 62
13. Key to Test Item Numbering 65
14. Test Item Data 66
15. Motion: Translational and Rotational Hierarchy 74
16. Velocity and Falling Bodies Hierarchy 75
17. Force Hierarchy 76

LIST OF TABLES (Contd.)

Table Page

18. Acceleration Hierarchy 77

19. Oscillation Hierarchy 78

20. Correlations of Cluster III Items 80

21. Correlations--Levels of Significance 82

CHAPTER I

INTRODUCTION

The Problem

The emphasis of many science projects has been on concept learning with an emphasis on laboratory work. One of the ways to provide an environment for concept learning is individualized instruction which is laboratory oriented. This mode of instruction can also provide the teacher with much time to interact with individual students and small groups. The student can have an opportunity to explore interests in greater depth, to self-pace his learning, and to adjust some of his experiences to his learning style.

The focus of this study was to assess the use of an individualized laboratory oriented high school physics program. The program assessed was one that was being used in two Black Hawk County schools in the State of Iowa during the 1969-70 school year. This program was individualized in that the students self-paced themselves through laboratory activities. In a sense, the materials were programmed since there was a specific sequence of laboratory investigations that they were to explore. Some additional optional laboratory activities were provided for those desiring to work at a "higher level."

Program content was logically arranged in a conventional way.

Great emphasis was placed on models as "symbolic organizers." The use of graph models, sentence models, data table models, diagram models, and descriptive models was introduced and developed early in the program before the formal introduction of the subject matter content.

Need for the Study

The assessment of this self-pacing laboratory approach to the teaching of high school physics was considered desirable at this time because there was much current interest in individualized instructional materials. This interest stemmed from many desirable attributes of this type of instruction (Glaser and Resnick 1972, Ashenfelter 1969, Koser 1969, Richard 1969, Champagne 1970).

Teachers appeared to like this mode of instruction because it freed them to become actively involved with the specific learning problems of individuals and small groups. It was also seen as a way to challenge all students. The more able student could work more rapidly without waiting for the slower students to catch up and the slower students were not frustrated by constantly attempting to keep up (Glaser 1969, Ashenfelter 1969, Koser 1969, Richard 1969).

Students have often tended to prefer individualized instruction. They could set their own goals and challenge themselves to learn at a rate commensurate with their ability. Interests could also be explored in greater depth when certain aspects of the curriculum were of greater interest to them. After a period of absence, the student could start where he had finished. There was no great need to catch up or to review material that had been discussed. There also existed the opportunity to sequence his own experiences or adjust some or all of his experiences to a particular learning style (Ashenfelter 1969, Koser 1969).

In summary, it may be said that individualized instruction can free the teacher to become more actively involved with students and can give the student more opportunity to take active responsibility for the learning process (Richard 1969, Ashenfelter 1969, Koser 1969).

Programs of this type seem to hold much promise. Evaluative studies of them are necessary to determine outcomes. This evaluation can be utilized by the course writer as a basis for possible program revision. It can also serve as a basis for assessing strengths and weaknesses of the program for those educators considering its possibilities for introduction in their schools.

Physics Enrollments

The decreasing percentage of students enrolled in high school physics classes has been a concern of science educators for some time. The percentage of high school students enrolled in physics decreased from 25.7 percent in 1948 to 20.5 percent in 1964 (Simon and Grant 1970).

During the past nine years, at the Malcolm Price Laboratory School where this program utilizing the self-pacing laboratory approach to teaching high school physics was being developed, the percentage of students taking physics had increased from approximately 20 to 44. The percentage increase at Columbus High School, where the program had been used two years, was 30 between the 1968-69 and the 1969-70 school years.

Alternative programs appear to be needed and desired. Moore, (1968:337), stated: "In spite of the tremendous success of this project, (Physical Science Study Committee Physics) several science educators still feel that more than one or two physics courses should be available for use by secondary schools."

Fletcher Watson, (1967:212), made a similar but more forceful statement when he said: "Why the schools need additional physics courses can be answered by looking both at the science enrollments (decreasing percentage taking physics) in secondary schools and the increasing importance of physics in our society."

These concerns about selection of physics courses and the decrease in the percentage of high school students taking physics were other events which prompted the investigator to study this physics course.

Problem, Sub-Problems, and Hypotheses

The general problem of this study was to ascertain whether these instructional materials that utilized a self-paced laboratory approach to conceptual learning of physics were suitable for the students enrolled in the course. The specific problems studied were:

1. What short-term and long-term learning result from use of the materials?
2. What student characteristics are related to learning outcomes?
3. What characteristics of the materials are related to learning outcomes?

The null hypotheses tested by this investigator were organized by specific problems as stated above. The acceptance or rejection of hypotheses was established at the .05 level of significance.

Hypotheses concerning short and long-term learning

1. There is no significant correlation between the Unit I or II Test Scores of the sample and the Equated Final Test Score.
2. There is no significant correlation between the Unit I or II Test Scores of the sample and the score on items of that Unit appearing on the Final Test.
3. There is no significant correlation between the time in weeks spent by the sample on Units I or II and the Equated Final Test Score.
4. There is no significant correlation between the time in weeks spent by the sample on Units I or II and the score on items of that Unit that appeared on the Final Test.
5. There is no significant correlation between the total number of materials Parts completed by the sample and the difference between items correct on the Final Test and Part Tests that appeared on both.
6. There is no significant correlation between the total number of materials Parts completed by the sample and the Equated Final Test Score.
7. There is no significant correlation between the items correct on the Part Tests by the sample and the same items appearing on the Final Test.

Hypotheses concerning students

1. There is no significant correlation between intelligence quotients of the sample and Unit I or II Test Scores.
2. There is no significant correlation between intelligence quotients of the sample and the time in weeks spent on Units I or II.
3. There is no significant correlation between intelligence quotients of the sample and the total number of materials Parts completed.
4. There is no significant correlation between intelligence quotients of the sample and the Equated Final Test Score.
5. There is no significant correlation between the four scores of the Iowa Test of Educational Development used and Unit I or II Test Scores.
6. There is no significant correlation between the four scores of the Iowa Tests of Educational Development used and time in weeks spent on Unit I or II.
7. There is no significant correlation between the four scores of the Iowa Tests of Educational Development used and the total number of materials Parts completed.
8. There is no significant correlation between the four scores of the Iowa Tests of Educational Development used and the Equated Final Test Score.
9. There is no significant correlation between the eight individual types of the sample indicated by the Myers-Briggs Type Indicator and the Unit I or II Test Scores.
10. There is no significant correlation between the eight individual

types of the sample indicated by the Myers-Briggs Type Indicator and the time in weeks spent on Unit I or II.

11. There is no significant correlation between the eight individual types of the sample indicated by the Myers-Briggs Type Indicator and the total number of materials Parts completed.
12. There is no significant correlation between the eight individual types of the sample indicated by the Myers-Briggs Type Indicator and the Equated Final Test Score.

Hypotheses concerning materials

1. There are no learning hierarchies in the materials found by analysis of conceptual behavior of students on test items.
2. There is no significant correlation between the Unit I or II Test Scores of the sample and the time in weeks spent on each of those Units.
3. There is no significant correlation between the time in weeks spent by the sample on Unit I and that spent on Unit II.
4. There is no significant correlation between the time in weeks spent by the sample on Units I or II and the total number of materials Parts completed.

Definitions

Certain terms used by this investigator necessitated defining to avoid confusion as to their exact meaning in this study. [illegible] terms are as follows:

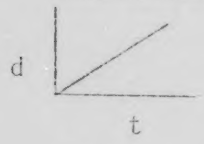
a. Part: A set of activities to be utilized by the student.

b. Concept: "As a working definition we may say that a concept exists whenever two or more distinguishable objects or events have been grouped or classified together and set apart from other objects on the basis of some common feature or property characteristics of each" (Bourne 1966:1).

c. Processes of science: Human performance inquiry skills incorporated by the learner with existing knowledge and experience to investigate new situation, i.e., observing, recording data, measuring, using space/time relationships, using numbers, communicating, investigating, inferring, classifying, interpreting data, predicting, controlling variables, defining operationally, formulating hypotheses, formulating models, and experimenting (AAAS 1966).

d. Model: A symbolic organizer that is an approximate representation of reality, i.e., graph models, sentence models, data table models, diagram models, and descriptive models. (See examples below.)

Graph Model



Sentence Model

$d = vt$

$F = ma$

Data Table Model

d in feet	t in sec
2	1
4	2
6	3

Diagram Model

A map, vector diagram or sketch.

Descriptive Model

A written description of an observation or series of observations.

e. Learning hierarchy: A succession of behaviors in instructional units. Certain behaviors are precursors of a terminal behavior (Gagne and Paradise 1961).

f. Success: The favorable termination of learning experiences.

g. Sample: The forty-eight students enrolled in the physics program at Columbus High School.

h. Score on Unit I Test: The number that indicated the questions answered correctly of the forty-six multiple choice items that appeared on a test covering Parts 2 through 10.

i. Score on Unit II Test: The number that indicated the questions answered correctly of the forty-six multiple choice items that appeared on a test covering Parts 11 through 19.

j. Part Score: The number that indicated the questions answered correctly on the Part Tests completed that later appeared on the Final Test. (There was one item on each Part Test that later appeared on the Final Test.)

k. Final Test Score: The number that indicated the questions answered correctly on the Final Test of the Program. (Students were instructed to answer only as many test items as they had completed program Parts. Only items taken from a Part Test they had completed were corrected.)

l. Equated Final Score: The number that was obtained by multiplying the number thirty-six (the number of items on the Final Test) by the ratio of appropriate items correct to the appropriate items corrected. (The number of appropriate items was determined by the number of program Parts completed and items were sequenced to follow the program and one item from each Part Test appeared on the Final Test.)

m. Equated PSSC Score: The number that was obtained by multiplying the number eighty (the number of items on the PSSC Final Examination - Form F) by the ratio of appropriate items correct to the appropriate items answered. Thirty-eight items of the eighty were selected as appropriate to the program materials and they were sequenced to follow the sequence of materials Parts. The students were instructed how many to attempt based on Parts completed and only that appropriate number was corrected.

n. Learning: "Learning is a change in human disposition or capability, which can be retained, and which is not simply ascribable to the process of growth" (Gagne 1965:5).

Delimitations of the Study

The study was delimited in the following ways.

1. The high school included in the study. Columbus High School of Waterloo, Iowa, was selected for assessing the self-pacing laboratory oriented high school physics program because it was utilizing the materials. This school was also selected because of its accessibility to the investigator who was teaching at the University of Northern Iowa.
2. The period of time encompassed by the study. This period was the 1969-70 school year.
3. The students included in the study. The study sample consisted of the 48 students at the Columbus High School.

4. *Materials used in the study.* The materials used were those available that had been developed at the Malcolm Price Laboratory High School.

Limitations of the Study

Based on the research design used and the delimitations established, the following limitations should be considered.

1. *The high school included in the study.* Findings can not be generalized beyond the one school used in the study.
2. *The students included in the study.* The sample was limited by the students who enrolled in this physics program in the one high school. Forty-eight students enrolled in the physics course at Columbus High School.
3. *The administration of evaluation instruments.* All physics tests were administered by the teacher of the program in the classroom. Written directions were provided with each test. The Myers-Briggs Type Indicator was administered by the guidance counselor of the school. The guidance counselor was provided with the publisher's manual for administering the instrument. It is possible that administration would have influenced results.
4. *The administration of the Iowa Tests of Educational Development.* The Iowa Tests of Educational Development were administered by the personnel of the school as part of the regular testing program.
5. *The administration of mental abilities tests.* The intelligence test was administered by the personnel of the school as part of the regular testing program.

6. Parts and Units completed by the students. The number of Parts and Units of the program completed and Part Tests and Unit Tests taken determined the extent to which the program was assessed.

Assumptions

The following were assumptions of the program or the investigator.

Assumptions of the program assessed

1. Sequential ordering of concepts. The physics course should have an orderly sequence of concepts that build upon previous experiences and concepts.
2. Development of the processes of science. The physics student should experience science as the scientist experiences science. Inquiry, problem solving, and discovery should play a dominant role in the course.

Assumptions of the investigator

1. Administration of tests. The counselors and teachers of the course were assumed to have the education and experience to administer the tests properly since they were duly certified by the State of Iowa Department of Public Instruction.
2. Data collected from cumulative folders. The cumulative folders were utilized to yield intelligence quotients and Iowa Tests of Educational Development scores on the Background in the Natural Sciences Test, Reading in the Natural Sciences Test, Quantitative

Thinking Test, and the Composite. These data were assumed to be valid.

Overview of the Study

This study was concerned with the evaluation of a self-pacing laboratory approach for teaching high school physics as used in one Black Hawk County, Iowa school. The period of time involved was the 1969-70 school year. The Columbus High School utilized the physics program studied. The program materials were written by Walter Gohman of the Malcolm Price Laboratory School. Mr. Gohman had been writing, using, evaluating, and rewriting the materials for approximately eight years previous to this study.

Summary and overview of chapters to follow

This chapter presented an introduction to the problem to be studied, need for the study, and some background information on physics enrollments. The general problem was stated and sub-problem hypotheses were described concerning short-term and long-term learning results, student characteristics related to what was learned, and materials characteristics related to what was learned. Terms were then defined; delimitations, limitations, and assumptions stated; and an overview of the study presented.

Chapter II presents an examination of the literature pertaining to physics enrollment data and psychological factors related to motivation, self-paced learning, structure of learning, hierarchy based learning materials, and personality factors.

Chapter III presents the design of the study. The selection of the sample school and sample teacher, analysis of content of materials, selection and evaluation of instruments, collection of data and analysis of data are discussed.

Chapter IV presents the findings about concepts and processes of science found in the materials, sample characteristics, and pre-test and post-test sample variance. Performance characteristics related to test scores, learning hierarchies, and analysis of hypotheses is also presented.

Chapter V presents the major findings concerning concepts and processes of science, characteristics of the sample, predicting success with materials, and concept hierarchies. Findings related to the hypotheses on short and long-term learning, student characteristics related to learning, and materials characteristics related to learning are discussed. Recommendations are also made for changes in the materials and further research.

CHAPTER II

REVIEW OF RELATED LITERATURE

This chapter has two sections. The first section examines physics enrollments and factors related to physics enrollments. The second section explores the psychological factors of motivation, self paced learning, structure of learning, hierarchy-based learning materials, and personality factors.

Physics Enrollments

The concern about a dwindling percentage of students enrolled in physics in high school is not a recent one. Lefler (1953:74), stated: "Although physics enrolls a smaller percent of the pupils in high school than in earlier years, the actual number of pupils taking physics has not changed significantly through the years."

In a publication by the American Institute of Physics (1960), it was indicated that only about one-fourth (25 percent) of the high school graduates studied physics and that this ought to be doubled within five years. This goal was not achieved. The percentage of students enrolled in physics actually dropped to approximately 19 percent in 1965 (Simon and Grant 1970). This same year Iowa had 9,094 students enrolled in physics at the beginning of the 1964-65 school year (Iowa Department of Public Instruction 1965). Enrollments in grade twelve that year were 42,551 (Iowa Department of Public Instruction, Part 1 1970). The percentage of students enrolled in physics was approximately 21 percent of the grade twelve enrollment.

During the 1969-70 school year there were 7,406 students enrolled in physics (Iowa Department of Public Instruction, Part 3 1970). The grade twelve enrollment was 45,357 (Iowa Department of Public Instruction, Part 1 1970). Enrollments in physics were down to about 16 percent. This was not only a percentage decrease but a sizeable decrease in the number of students enrolled in physics. If these figures were representative of what was happening nationally, for which more recent figures were not available, the trend toward decreasing physics enrollments had not changed. Certainly, the need for citizens to be informed in physics is not less today.

Psychological Factors

Motivation

It has usually been assumed that motivation has been a significant factor for learning. The learner has been kept at work by the teacher using promises of reward or threat of punishment. Motivation has also arisen as a result of the learner's own goals, interests, and curiosity, or it may have been any combination of the above listed factors. However, it has been pointed out that the studies of psychologists do not support a "straight-forward relationship between motivation and learning' (Sears and Helgard 1964:182). The problem appears to be one of lack of clarity between learning and performance.

Fowler (1965) and Berlyn (1960) found that those experiences eliciting and maintaining curiosity and behavior were those of orienting, approaching, investigating, and manipulating. These variables appeared to be related to what deCharms and Carpenter (1968) referred to as "Origin" which denoted that the individual originated his own behavior. This is opposed to "Pawn" behavior which denoted powerlessness. Laboratory studies by Kuperman (1966) and deCharms, Daughtery, and Wurtz (1965) investigated the origin-pawn variable experimentally and found with respect to the origin model that the subjects, "liked the origin model best," "became more involved," "chose to continue when interrupted," "completed it more elegantly," and recalled a nonsense name for it more frequently a month later. It appeared that the origin dimension had stronger effects on behavior.

Bruner, Goodnow, and Austin (1967:17) reported: "Cognitive frustration within tolerable limits, helps keep search-behavior going. The 'insight' experience leads to new bursts of testing activity."

Shuftel, Crabtree, and Rushworth (1960), based on their studies in the elementary school, found that problem-solving and creativity was aroused by having the teacher establish a classroom climate for the development of a healthy self-concept, by evoking problems not immediately apparent to the learner, and by stimulating a problem-solving climate that included a search for plausible answers by the use of experience units, construction activities, science experiments, group work, dramatic play, and role playing.

In summary, there appears to be evidence that those behaviors or activities that are self-originated are more intrinsically motivational and "insight" experiences stimulate interest.

Self-paced learning

Self-paced learning is one way of individualizing instruction. It can take many forms, including linear programmed instruction which is restrictive and branched programming which is less restrictive.

Glaser and Resnick (1972:242) in discussing learning and individual differences stated:

> . . . there may be every reason to believe that theories which are most amenable to incorporating individual difference parameters will emerge as the most powerful theories of learning. From the point of view of education, there is a long-standing desire to design instructional systems that are "individualized" and provide educational alternatives for the various needs and talents of the learner. Educators have employed various kinds of ungraded and track systems, but the degree of adaptation has never been enough to force answers to the underlying problem of the interaction of individual differences with instructional variables.

Self-pacing is one means of adjusting treatment of aptitude by allowing the learner to adjust the materials to his rate of learning.

Gagne (1967:25) indicated that learning under similar instructional conditions would be fairly consistent. He stated: "My working hypothesis is that, when several intellectual tasks are to be learned under much the same instructional conditions, there will indeed be some individual consistency in time needed to reach the criterion." This was contrary to the conclusion of Woodrow (1964) and Humphreys (1960) who concluded that rate of learning is entirely inconsistent from one task to another. If there is inconsistency in rate of learning, self-paced instruction has promise.

PSSC Physics was taught as a self-paced learning approach by Ashenfelter (1969) to two classes of eleven to eighteen students at the University of Illinois Laboratory High School. He established ground rules in addition to regular laboratory reports and tests. Students were expected to work near capacity, to hand in a weekly log of work, and to complete the course.

After eighteen weeks, seventy-five percent of the students wanted to continue this approach. The advantages cited were that students could self-pace as needed, rarely missed discussion through absence, could schedule their own time for tests, and could interact more with other students. Also reported as advantages were that the instructor was more available for individual help and that individual or small-group problems could be more fully explored.

Intermediate Physical Science was independently scheduled and sequenced by Koser (1969). This approach consisted of a sequencing of laboratory problems, a written evaluation of them, and the end-of-chapter home, desk, and laboratory problems. Students worked in groups of two or three. Reported findings were that pressure of keeping up was removed from slower students, frustrations of better students waiting on slower students was released, pressure on the instructor increased, and students got more positively involved at the beginning of the class period. Although another teacher-paced approach was ahead in number of experiments completed, the general feeling of teachers and students was that independent scheduling was the better arrangement.

Biology was individualized by Richard (1969) at the Colorado State College Laboratory School. The Biological Science Study Committee Green Version was used with two matched tenth grade classes of thirty students each. Time blocks for completing required activities were established, but the experimental group individuals were allowed to sequence the activities. The hypothesis that there would be no significant difference between the two groups at the .01 level when compared with national norms on the BSCS Achievement Tests was accepted. Analysis of student opinions was that self-directed students liked the approach while the non self-directed had difficulty organizing their work.

A program of Individually Prescribed Instruction in science for the primary grades that will eventually be developed through grade nine was described by Champagne (1970). The individualization was largely self-pacing and had mini-placement tests. Simmons and Garvue (1969) felt the program might produce individuals who were more self directed and independent.

In summary, self-paced learning appears to hold promise for the learner. The majority of students in the studies cited tended to favor the approach because it removed pressure from the slow learner and frustration of waiting to proceed for the rapid learner. Self-paced instruction may also allow the learner to adjust his rate depending upon the intellectual task. Differences for learning rate between individuals and within the individual from task to task may be adjusted.

Structure of learning

Questions regarding characteristics of the learner and how these relate to the way individuals learn have also been raised. The structure of learning itself will now be examined from different points of view. Guilford (1968) theorized that general intelligence is made up of numerous specific factors and that these factors play important roles in the learning process. Two individuals with similar general intelligence quotients were considered to generally differ substantially in the factors comprising the common quotient and thus differ in the way they learned. Each factor was considered to be a unique ability and was theorized to fall into one of three categories--operation, product, or content. The content category and product category were considered to interact. Guilford (1968:55) stated: "I sometimes think of the content categories as being the kinds of raw materials of information and the product categories as the kinds of manufactured articles that the organism makes of the raw materials." The operation category was considered to include those factors that processed the content to produce the product. The four to six factors in each of the three categories were then theorized to interact in a three dimensional system to produce approximately 120 possible combinations.

The content category contains figural (sensory perception of properties), symbolic (perception of signs, letters and digits), and semantic factors (perception of verbal meanings or ideas). Symbolic abilities are considered important in the field of mathematics and semantic abilities in verbalization. The physics program assessed placed great emphasis on symbolism such as data table models, graph models, and sentence models. It was thus expected that the Iowa Tests of Educational Development Quantitative Thinking Test scores would be better predictors of success with the materials than general intelligence scores because success with both required symbolic abilities.

The content category perceptions are then operated on (operation category) by the factors of evaluation, convergent and divergent production, memory, and cognition. Cognitive operations dealt with discovery, knowing, and rediscovering. The operation of convergent production is considered important in arriving at the right answer on multiple-choice test items. Both the Quantitative Thinking Test items and the test items written to assess the students progress with the materials were multiple-choice items. Convergent production abilities were thus expected to be important in arriving at the correct answers on both tests. This was expected to aid in making Quantitative Test scores better predictors of success with the materials as determined by test scores.

The product category included units, classes, relations, systems, transformations, and implications. Cognition of these products was considered important in discovery. Thus, the learner was considered a processor of information and learning was considered the discovery of information. Stored information was considered necessary for transfer and the condition for transfer was the similarity of task.

Gagne (1965) takes a different approach to learning theory. His theory focuses on different types of learning and each type is theorized to build on learning that took place in a simpler type. This learning theory is hierarchical.

Internal capability is considered necessary for learning from external stimuli. The degree of learning depends on prior capabilities. In his theory (Gagne 1965) stimulus-response learning can be connected through the learning process of chaining. The chains can be utilized for verbal-associate learning. Verbal-associate learning can then be utilized for multiple discrimination learning which is utilized in concept learning. Concepts are associated in principle learning, which in turn, is necessary for problem solving.

Concept learning involves putting things in a class and [illegible], responding to dissimilar stimuli with a similar response. The conditions within the learner for concept learning would be prior stimulus-response, chaining, verbal-association, and multiple discrimination learning. Situational conditions for concept learning are chains with a common final link that are presented in close time succession, new situations or instances with an old final link, and reinforcement. The concepts learned are considered to free the individual from control by specific stimuli.

The learning of concepts stems from experience that result from stimuli that are "classified as a member or a nonmember of a concept class" (Glaser 1968:42). This abstract process is probably never complete although single concepts may be quite stable. The learning of concepts and the relationship between test items of the same and different levels of difficulty were examined to determine the degree to which a concept was learned.

Verbal learning typically used four types of tasks in assessing learning: serial learning, extended serial learning, paired-associate learning, and free recall learning. In a review of research findings dealing with distributed practice, Hall (1971:222) stated that "the experimental evidence appeares to be unequivocal in demonstrating the superiority of distributed practice in serial learning tasks." Distributed practice was often found to be a positive factor in pair-associate learning also but not to the extent evidenced in serial learning.

Hypothesis-testing theories view the learner as active in selecting ways to operate on his environment (Bruner, Goodnow, and Austin 1956). The learner is viewed as actively choosing some tentative hypothesis to test in forming and utilizing concepts. Then decisions are made by the learner that require further decisions that eventually lead to the acceptance or rejection of the hypothesis. The use of hypothesis-testing appears to require a minimal background of learning that can be transferred to a new conceptual problem (Bourne 1966). Focusing strategies were found to vary and be dependent on the problem factors and previous learning.

Hypothesis testing was placed at one end of a continuum by Bourne (1966:43) when he stated:

> It is possible to think of nonmediated S-R, mediated S-R, and hypothesis-testing theories as representing some sort of continuum of behavioral sophistication. Indeed, mediational and hypothesis-testing theories seem to differ mainly in technical language, and except for the manner in which internal processes are initiated--mediators through some stimulus cuing event and hypotheses by a subject-determined selection process--are often directly translatable. The theories are not necessarily incompatible. In fact, conflicts seem to arise only when a theorist, committed to a single position, insists that his theory holds for all behavior no matter what the circumstances.

The functions of mediators was described by Bourne (1966:35) when he stated:

> . . . mediators provide the kind of building blocks from which so-called abstract and/or hierarchically arranged concepts can be formed. The most basic concepts seem to be those wherein simple stimulus attributes corresponding to physical dimensions are the fundamental elements. Mediational representations of these groupings can be combined complexly so as to produce concepts with no physical referents or instances; that is, concepts defined solely in the abstract with words. Theoretically, mediationally represented concepts can be combined and

> arranged into higher-order, more inclusive groupings interminable except for limitations on the intellect of the individual dealing with them.

In summary, Quantitative Thinking Test scores were expected to be very significant predictors of success with the materials because both required symbolic and convergent production abilities. The relationship of success with items of similar and different difficulties of concepts was also examined.

Hierarchy based learning materials

One of the ways of organizing the learning task is to develop learning hierarchies. In developing a learning hierarchy, a terminal task is selected, hypothesized subordinate tasks are selected that are considered precursors to the terminal task, and the learning hierarchy is tested to determine if positive transfer from one level of the hierarchy to the next has occurred (Gagne and Paradise 1961). These hierarchies stress what the learner is able to perform. Positive transfer within a learning hierarchy was found by Gagne and Paradise (1961); Gagne, Mayor, Garstens, and Paradise (1962); and Merrill (1965).

The number of trials necessary to learn a task when the learner started with the simpler tasks or with the terminal task was investigated by Resnick, Siegel, and Dresh (1971). They found that fewer trials were needed when the learner progressed from the simpler task to the terminal task. Those learners that were successful in beginning with the terminal task were found to have acquired some of the subordinate tasks in the process.

A validated learning hierarchy appears to hold promise for individually prescribed instruction. Glaser and Resnick (1972) support the idea that the performance of the learner with tasks within the hierarchy can be tested and the learner placed in the learning hierarchy at the task where optimal learning will take place.

Conclusions drawn from studies on learning hierarchies appear promising. Gagne and Paradise (1961:15) found a decreasing pattern of correlations between "relevant basic ability factors and rate of learning" as the learner progresses through the hierarchy and that rate of learning increasingly depends on acquired subordinate behaviors. Walbesser (1968) concluded that the longer the learner was in the program "Science--a Process Approach" the more successful he was. He also found that the acquisition of desired behaviors was not biased by socio-economic conditions.

In summary, positive transfer of learning was highly evidenced in learning hierarchies. The terminal behavior in the hierarchy was achieved with the fewest trials if the learner started with the simplest behaviors and progressed sequentially to the terminal behavior. Some learners are able to achieve the terminal behavior without progressing through the learning hierarchy. When they do, there is evidence that some subordinate behaviors have been learned in the process. As the learner progresses through a learning hierarchy rate of learning was found to be increasingly dependent on acquired subordinate behaviors and decreasingly on "relevant basic ability factors." The longer a learner was in a learning hierarchy the more successful he was in it. The acquisition of behaviors in a learning hierarchy was not found biased by socio-economic conditions.

Personality factors

This section deals with intelligence and type behavior as factors associated with concept learning. Also included are competencies that are related to certain modes of instruction.

The role that intelligence plays in conceptual learning is generally assumed to be quite strong. In fact, conceptualizing is even often thought of as a factor of general intelligence. A review of the literature by Bracht (1970) resulted in his concluding that intelligence scores and similar general ability measures and general achievement measures were not useful variables in determining alternate treatments for subjects in a homogeneous age group. However, the measures did correlate substantially with achievement in most school tasks. Specific factors that comprise general intelligence yield more promising results. A study of loading of some different factors of intelligence on learning by Guilford (1968:72) resulted in his stating:

> Of the four SI (Structure of Intellect) operation categories involved in this study, that of the memory abilities appeared to make the greatest contribution to learning......... Meaningful or semantic information is more readily remembered than other kinds, and it is often found in memory experiments that employ figual or symbolic information that S's (subjects) translate such information into more readily remembered forms. But in this experiment, there were some signs of translation in the other direction as well. A human subject is a very resourceful creature.

In reporting on a study of factors that were statistically significant in predicting success in ninth grade algegra, Guilford (1968:183-84) stated:

> With only predictors that gave statistically significant contributions to prediction of achievement, some 12 different factors were found relevant. Most of these factors are from the symbolic category of the structure of intellect, very few

> are cognition factors and quite a number are evaluation factors: most of them deal with products of relations and implications.
>
> The implications of these findings for education are numerous. For one thing, we see the importance of SI abilities for dealing with classes (concepts) (Cuilford 1968:73).

The preference of individuals to choose a certain type of behavior such as extraversion or introversion, sensing or intuition, thinking or feeling, and judgment or perception has been studeid by Myers (1962). She found that scholastic potential appears to be associated with preferences for introversion and intuition, and that these types had the highest mean grade point average. A comparative study of type and intelligence was conducted by Myers (1962:44) with grade point average. Concluded was that a substantial portion of superior scholastic achievement cannot be attributed to intelligence when introvert-intuition types were compared with extrovert-sensing types. Hypothesized was that introvert-intuition types had a greater "natural interest in scholastic activity and that ES (extrovert-sensing) types have the least."

A quantitative study comparing audio-tutorial and traditionally organized biology instruction at the college level was reported by Szabo and Feldhusen (1970). Success in the courses was compared to intellective, personality and biographical variables. The top third of the audio-tutorial group in achievement had significantly higher mathematics reasoning skills and past science achievement. The high achievement subgroup of the traditionally--organized course had verbal aptitude, mathematical computation skills, and restraint (tendency toward introversion) significantly related to success. No intellective predictors exhibited a significant relationship with success in the audio-tutorial course.

A curriculum is typically developed from a written set of objectives. These objectives vary and thus the curriculum and evaluation varies. Widely accepted standardized instruments are biased depending on the objectives they are designed to measure. Thus it was not surprising that Hipsher (1961), Heath and Stickell (1963), and Wallace (1963), found that students studying respectively; Physical Science Study Committee Physics, Chemical Bond Approach, Chemistry--An Experimental Approach, and Biological Science Curriculum Study Biology, did better on tests designed for that specific curriculum than did those students who were studying some other program. Harvard Project Physics (1969) reports similar results.

Osler and Fivel (1961) studied conceptual behavior using two groups of children at each of the ages of six, ten, and fourteen years. One group had intelligence quotients between 90 and 109 while the other had quotients above 110. Some subjects showed gradual improvement while others arrived at solutions suddenly. Rapid concept learning was found associated with age and intelligence. The interpretation of this was that some used stimulus-response associations while others used hypothesis testing. Sudden learning, hypothesis testing, was much higher among the higher intelligence group and older subjects. The researchers reasoned that the more intelligent and older subjects may be better able to use symbolic or mediational processes. A furter study by Osler and Troutman (1961) tested the prediction that more intelligent individuals tend to use mediational processes. The conclusion was affirmative.

In summary, it appears that general ability factors are not useful variables in determining alternate treatments for subjects in a homogeneous age group. Memory abilities of intelligence appear to be the greatest contributors to learning. Semantic information is most readily remembered but often found was figural or symbolic information. Algebra performance was best predicted by symbolic content, evaluation operations, and relations and implications products.

Introvert-intuition types were found related to scholastic potential.

Mathematics reasoning skills were found significantly correlated with success in audio-tutorial instruction but intraversion was significantly correlated with more traditionally-organized course.

More rapid working children up to fourteen years of age were found to use hypothesis-testing as opposed to stimulus-response for those progressing more slowly and this was positively related to intelligence and age

CHAPTER III

DESIGN OF THE STUDY

This chapter consists of sections dealing with the selection of the sample school and sample teacher, analysis of content of materials, selection and evaluation of instruments, collection of data, and analyses of data.

Selection of Sample School and Sample Teacher

The purpose in this study was to assess the use of a self-pacing laboratory oriented approach for teaching high school physics. The sample school where the study was conducted was selected because it was utilizing the physics program investigated and was close to the University of Northern Iowa where the investigator was teaching. The selection of the sample school determined the selection of the sample teacher.

Proximity of the sample school to where the investigator was teaching allowed a minimum of a weekly visit with the teacher to deliver evaluation materials, pick up completed materials, and report evaluation results. It was felt that this constant feedback of test results would encourage the students involved to work more effectively as test results were not used to determine grades. (For a copy of achievement report form, see Appendix D.)

The sample has been described here as the physics class at Columbus High School.

Analysis of Content of Materials

A listing of concepts and where they were introduced, developed, and utilized in the materials was not available. An analysis of concepts was thus felt necessary to describe the scope and sequence of concepts. The scope and sequence of concepts was constructed by the investigator by careful analytical readings of the materials. The Defense Documentation Thesaurus (1966) was utilized for basic organization and minimum established terminology. The concept chart was utilized in the construction of evaluation instruments.

The following statements describe the scope and sequence of the materials. Models, frames of reference, dimensional operations, vectors and scalars, direct and inverse variation, and mathematics used in the course, were found in Parts 2 through 9. Mechanics was treated in Parts 10 through 30. Wave motion was found in Parts 23 through 35, and Part 37 introduced electricity and magnetism which was to be expanded by Parts yet to be written. (For information as to scope and sequence of concepts and a table of contents, see Appendix A.)

The processes of science incorporated in the program to be learned and utilized by the students were also analyzed and described. The processes of science analyzed were selected from the listing of AAAS (1966), and SCOPES (Finsand and Potter 1968). These processes of science were organized around the process of model formulation as the writer of the course placed great empahsis on the understanding, development, and analysis of models. The processes were organized around diagram models (maps, blueprints, or sketches), data table models (gas mileage charts or distance-time charts), graph models (paired data plot such as the Dow Jones Averages), descriptive models (written or oral accounts), and sentence models (symbolic representation such as the Phythagorean Theorem). Processes of science were organized around inquiry when a specific model was not suggested. The analysis and listing of the processes of science were accomplished by a few analytic readings of the printed materials for each specific process of science described. (For a description and listing of processes of science, see Appendix B.)

The description and sequencing of processes of science organized around models were then utilized in the construction of evaluation instruments. This investigator felt that a test item should be valid for both concept and model utilized.

Selection and Evaluation of Instruments

The selection of instruments was based on the scope of the study. The decision was made to utilize data from instruments administered in the school as a part of the evaluation program where such were applicable. The three aspects on which data were collected were those concerning personal characteristics of the learner, the level of educational development of the learner, and performance on physics test items.

The evaluation instruments used in the study fell into categories of those already utilized by the school, those already developed but not used by the school, and those to be developed by the investigator.

Selected evaluation instruments utilized by the school on a regular basis

Group intelligence testing was done on a planned basis periodically in the school. One administration was made during the high-school years. These scores were used. The intelligence test used was the Henmon-Nelson. It has a reported reliability of .94 (Buros 1959).

The Iowa Tests of Educational Development were used in the school and administered in the early fall. Selected from this battery were the standard scores on the Background in the Natural Sciences Test, Reading in the Natural Sciences Test, Quantitative Thinking Test, and the Composite score. Reported reliabilities of these tests average .91 and standard error values average 1.75 (University of Iowa 1971).

Special evaluation instruments selected with previous use

The Myers-Briggs Type Indicator was chosen to determine the effects of behavior types on performance. This instrument was based on the theory that human behavior is quite orderly and consistent even though it appears random. Behaviors assessed were extraversion and introversion (E or I), sensing and intuition (S or N), thinking and feeling (T or F). and judgment and perception (J or P).

Split-half reliabilities reported in the manual for various groups generally fall between .75 and .90 for the paired preferences (Myers 1962:20). (A copy of the Myers-Briggs Type Indicator [F] is available on loan from the investigator.)

An instrument was constructed of selected PSSC Final Examination questions judged appropriate for the course. The test was constructed from the PSSC Final Examination - Form F (1964). Thirty-eight of the eighty items in the test were selected. They were selected as appropriate to individual Parts of the course by this investigator and the course writer independently. A conference was then held between them to jointly agree on test items to be used and the Parts they evaluated. These were then ordered to follow the materials sequence. Only those items evaluating Parts the student had finished during the school year were corrected. Specific data on item difficulty was searched for by the investigator but not found and requested from the Educational Testing Service. A letter of reply stated that such information was not available. (A copy of the test constructed from the PSSC Final Examination - Form F questions is available on loan from the investigator.)

Evaluation instruments developed by the investigator

In order to evaluate the specific objectives of the program, it was necessary to develop instruments based on these objectives.

Thirty-six instruments were constructed to evaluate understanding of concepts. The thirty-six instruments, one based on each Part of the course, were constructed by analysis of concepts developed in that Part and models utilized in that Part and previous Parts. These items were then submitted to two staff members of the Physics Department at the University of Northern Iowa who served as expert readers. Each test was comprised of 12 or 6 multiple choice items with four possible answers and one correct answer. The number of test items to evaluate each Part was based on the number of concepts reportedly developed in that Part. Shorter and less comprehensive Parts were evaluated with six-question tests. (A copy of each of the thirty-six Part Tests is available on loan from the investigator. Terminology used follows that of the physics materials.)

Four instruments were constructed to evaluate understanding of concepts upon completion of each unit. The four Unit Tests were comprised of forty-six items. Five items were selected from each of eight Part Tests and six items were chosen from the ninth Part Test to give an even number of items. Reliabilities (Kuder-Richardson #20) were established for each Unit Test and item difficulty and discrimination indices established for each item using students studying HPP and PSSC in classes at Cedar Falls Community High School. Unit I Test analysis based on a sample of 84 students produced a mean of 25.04, a standard deviation of 6.63, and a reliability of 0.81. Unit II Test analysis based on a sample of 21 students produced a mean of 17.29, a standard deviation of 4.29, and a reliability of 0.56. Unit III Test analysis based on a sample of 27 students produced a mean of 22.19, a standard deviation of 7.01, and a reliability of 0.83. Unit IV Test analysis based on a sample of 33 students produced a mean of 24.36, a standard deviation of 6.07, and a reliability of 0.75. (A copy of each of the four Unit Tests is available on loan from the investigator.)

A Final Test, also used as a pre-test, was constructed to assess concepts at the end of the school year. The Final Test was constructed of one item from each Part Test. The items were chosen from those that were used in the Unit Tests on the basis of the best combination of item discrimination and approximately fifty percent difficulty as determined from administration to the non-sample students at the Cedar Falls Community High School. Students were instructed to complete all test items when administered as pre-test and as many items as they had parts of the course when administered as the Final Test. (A copy of the Final Test is available on loan from the investigator.)

Reliabilities were not established for Part Tests and the Final Test. They were considered satisfactory because almost half of the Part Test items appeared on the Unit Tests and all Final Test items were selected from the Unit Tests.

The funneling of questions from the Part Tests to the Unit Tests and finally to the Final Test is presented in Table 1, p. 38.

TABLE 1

FUNNELING OF TEST ITEMS TO FINAL TEST

Part Tests		Unit Tests		Final Test
Part	Item	Unit	Item	Item
2	3	1	3	1
3	10	1	9	2
4	8	1	15	3
5	1	1	16	4
6	3	1	22	5
7	5	1	26	6
8	9	1	35	7
9	6	1	40	8
10	2	1	42	9
11	1	2	1	10
12	3	2	8	11
13	7	2	13	12
14	4	2	19	13
15	1	2	21	14
16	5	2	30	15
17	6	2	32	16
18	2	2	37	17
19	4	2	43	18
20	10	3	5	19
21	6	3	10	20
22	1	3	11	21
23	3	3	18	22
24	8	3	25	23
25	3	3	28	24
26	2	3	32	25
27	1	3	36	26
28	1	3	41	27
29	5	4	4	28
30	2	4	7	29
31	2	4	12	30
32	2	4	17	31
33	4	4	23	32
34	2	4	27	33
35	2	4	32	34
36	1	4	36	35
37	5	4	45	36

Collection of Data

Procedures

Procedures for collection of data were cleared with the school administration. The names of students enrolled in the course, sex, grade classification and intelligence quotients were obtained from the guidance counselor. Iowa Tests of Educational Development standard scores were also supplied by the guidance counselor about the middle of the school year when results were received after an early fall semester administration by school personnel as part of the regular testing program. (For a copy of the Sample Characteristics Form on which this data was collected, see Appendix C.) The guidance counselor also cooperated by administering the Myers-Briggs Type Indicator and the investigator scored them. All physics tests were administered by the teacher when the individual student had completed a Part or Unit or when the end of the school year was imminent. Written instructions were provided with each test and kept standard so directions by the teacher were not necessary. Part and Unit Tests completed were picked up weekly by the investigator, corrected by him, and results reported to the teacher as the number missed the following week. These scores were not used for grading.

Timetable of study

The sequence of the study was as follows:

September, 1969- Beginning of school
Administration of Myers-Briggs Type Indicator
Delivered Part tests and answer sheets

	Obtained class lists
	Established reliability of Unit Test I
	Administration of Part Tests begun as Parts finished
	Began weekly pickup of test answer sheets and result return
October, 1969-	Administration of Iowa Tests of Educational Development
	Administration of Unit Test as Unit finished
January, 1970-	Obtained sample characteristics data
April, 1970-	Established reliability on Unit Tests II, III, and IV
	Selected Final Test items
	Printed Final Test
June, 1970-	Administration of PSSC items
	Administration of Final Test
September, 1970-	Administration of pre-test to similar sample
October, 1970-	Administration of ITED to similar sample
January, 1970-	Obtained sample characteristics of similar sample

Analysis of Data

The analysis of Unit Tests was done by the Research Bureau at the University of Northern Iowa. The answer sheets were machine scored and a computer program was run that provided frequency distribution of scores; provided keyed item responses to foils for each item; provided item percentage difficulty; provided item discrimination; and provided means, standard deviations, reliabilities (Kuder-Richardson #20), sample size, and discrimination and difficulty analysis by items. This analysis of Unit Tests was used specifically to determine reliability of the Unit Tests and to select items for the Final Test. The selection of Final Test items was based on the criteria of selecting one item from each Part of the materials appearing on the Unit Tests that had a high discrimination index and approximate difficulty of fifty percent. The Final Test had, based on the administration of Unit Tests at the Cedar Falls Community High School, an average difficulty of .54 and discrimination indices of fair for four items, good for eleven items, and very good for twenty-one of the thirty-six items.

The use of the Instruction and Research Computer Center at The Ohio State University was arranged for by the investigator's adviser. A statistical program consultant was provided at the Center based on the programs desired to be used. This consultant provided assistance on specific program selection and programming. The Biomedical Programs of the Health Services Computing Facility at the University of California at Los Angeles were used exclusively on the advice of the investigator's adviser. The January 30, 1970, revision of the BMD03D was used for obtaining correlations when the number of variables was not great and the May 10, 1968, revision of the BMDX84 was used when the correlations between two hundred and ninety-three variables was needed. The January 13, 1970, revision of the BMDX70 was used to compute variances. Multiple regression was computed using the BMD02R.

A correlation matrix (BMD03D) was run to determine the relationship of sample characteristics, test scores, equated test scores, rate of progress, Part Scores, and other pertinent data to support or reject hypotheses. (For definitions of terms and how they were computed, check the section on Definitions in Chapter I, p. 7.)

Levels of significance of correlations were determined using "Table VI, Values of r for Different Levels of Significance" (Downie and Heath 1965:306). Degrees of freedom were established as N-2.

Variance (BMDX70) was computed between the sample (Columbus 1969-70) and the Columbus High School physics class of 1970-71 to determine if the two classes were comparable. Characteristics compared were intelligence quotients, and standard scores from the Iowa Tests of Educational Development (Background in the Natural Sciences, Reading in the Natural Sciences, Quantitative Thinking, and the Composite) administered during the years the respective sample and pre-test group were taking physics. These data were used because they quite consistently correlated significantly with test scores and progress of the sample. It would thus be possible to generalize to the 1970-71 pretest group any problems incurred by the sample.

Careful analysis of the data collected warranted the statement that these two groups were not significantly different at the .05 level of prediction in intelligence quotients, on the Iowa Tests of Educational Development standard score on the test Quantitative Thinking and on the Composite. They differed significantly, at the .05 level, only on scores on Reading in the Natural Sciences Test and Background in the Natural Sciences Test. Since these test scores were not found to be significant predictors of performance, the two groups were judged by the investigator to be comparable groups and any difficulties of the sample could be generalized to the 1970-71 group. The results of tests of variance are found in Table 2, on p. 43. The "X" variable is the 1969-70 sample and the "Y" variable is the 1970-71 group. While the "P Value" in vertical column eight indicates the 1969-70 sample and 1970-71 group are significantly different at the .02 level of significance in standard scores on the Background in the Natural Sciences Test and Reading in the Natural Sciences Test. The same values under pooled variance estimate and separate variance estimate do not indicate the two to be significantly different in standard scores on the Background in the Natural Sciences Test. The "P Values" of .61, .62, and .62 for Quantitative Thinking indicate that the sample and the class of the following year are quite similar in abilities in this area. Quantitative Thinking Test standard scores are the best predictors of Unit I Test Scores, Unit II Test Scores, and the Equated Final Test Scores with 33, 42, and 44 percent of variance accounted for respectively.

TABLE 2

VARIANCE

Columbus 1970-71 with Columbus 1969-70
(X, 42 cases with Y, 48 cases)

	Variable	Cases	Mean	Standard Deviation	Standard Error	F Value	P Value	Pooled Variance Estimate			Separate Variance Estimate		
								T Value	Degrees of Freedom	P Value	T Value	Degrees of Freedom	P Value
I.Q.	X Y	42 47	115.7 116.0	9.4 11.2	1.4 1.6	1.43	0.24	-0.14	87	0.89	-0.14	86.6	0.89
Background in the Natural Sciences	X Y	42 48	22.9 22.8	3.2 4.5	0.5 0.6	2.01	0.02	0.13	88	0.90	0.14	84.4	0.89
Reading in the Natural Sciences	X Y	42 48	24.6 27.3	4.4 6.2	0.7 0.9	2.01	0.02	-2.40	88	0.02	-2.45	84.41	0.02
Quantitative Thinking	X Y	42 48	25.1 25.7	5.2 5.6	0.8 0.8	1.16	0.61	-0.49	88	0.62	-0.49	87.70	0.62
Composite ITED	X Y	42 48	25.5 27.6	5.0 6.4	0.8 0.9	1.65	0.10	-1.70	88	0.09	-1.73	86.87	0.09

Multiple regression (BMD02R) was run in which test scores were used only as dependent variables and independent variables were only used as such. Independent variables included those factors which appeared on the basis of the analysis of correlations to be related to performance--intelligence quotients, ITED standard scores, weeks spent on Unit I and II, and total Parts completed.

Correlations (BMDX84) between individual performance on test items from Part Tests 2-23 and items from those Parts appearing on the Final Test were run. Levels of significance were established and those significant at the .05 level were used to determine if learning hierarchies existed in the program.

Summary

This investigation was designed to assess the use of a self-pacing laboratory approach for teaching high school physics during the 1969-70 school year. The sample consisted of 48 students enrolled in the program at Columbus High School in Black Hawk County, Iowa.

This chapter contained a description of how the sample school and teacher were selected, how the materials were analyzed for scope and sequence of concepts and processes of science, how instruments were selected or constructed and reliabilities established, how data was collected, and how data was analyzed.

Students were identified by number to avoid identification of individuals.

CHAPTER IV

THE FINDINGS

Introduction

This chapter contains a presentation, interpretation, and analysis of the data obtained through a careful examination of the printed program materials and the instruments used in the study. It contains sections on concepts and processes, sample characteristics, performance characteristics, learning hierarchies, and analysis of hypotheses.

Each section is presented, evaluated, and summated as a unit.

Concepts and Processes

Concepts included in the materials

The first eight Parts of the materials, Parts 2-9, introduced the student to the program, to the models with which he worked, to kinds of motion, to frames of reference, to dimensions and dimensional operations, to vector and scalar quantities, and to direct and inverse variation. The mathematics used by the student using the materials was also introduced and practically applied in these eight Parts. Some concepts of mechanics (motion, rotation, and velocity) were utilized in Parts 4 and 5 to introduce models appropriate to them

The concepts were, with some overlapping, organized in two broad areas--mechanics in Parts 10 through 30 and wave motion in 28 through 35. Electricity and magnetism in Part 37 introduced a third broad area that was in the process of being developed.

In the first broad area of mechanics, miscellaneous mechanics concepts were found in Parts 10 through 30. Fluid mechanics concepts were, in the main, found in Part 24. Thermodynamics concepts were dealt with in Part 25.

The broad concept of energy was used as the vehicle for an easy transition from mechanics to wave motion. Energy was introduced in Part 22 and continued through Part 30 with the transition from mechanics to wave motion taking place in a gradual manner from Parts 28 through 30.

The second broad concept area of wave motion had wave propagation concepts included from Parts 28 through 36. Acoustics concepts were treated in Parts 28 and 29 with optics concepts in Parts 30 through 36. Part 37 contained a review of ideas related to energy and introduced concepts of the third broad area--electricity and magnetism. (For a more detailed understanding of the scope and sequence of concepts and a table of contents for the materials, see Appendix A.)

Processes of science utilized in the materials

The processes of science were an integral part of the materials and received major emphasis throughout the content of the materials. The simpler processes of science, those appearing in approximately the first half of the listing, were developed early in the materials and then utilized as an integral part of the program from that point on. The more complex processes of science that required more advanced skills of inquiry and integrate the simpler processes of science were begun early in the program of studies and their development continued throughout it.

The sixteen processes of science were organized around data table models, graph models, sentence models, diagram models, descriptive models, and methods of inquiry. Formulating these models received great emphasis early in the program materials as the important method to organize observations to discover relationships in nature. The processes of science were listed under inquiry when no model type was suggested and laboratory activities were less stuctured and more open-ended. Processes listed under inquiry were more prevalent in the latter Parts of the materials when activities were more open-ended.

Processes were organized so that each process of science could be treated separately and organized under the five separate models and inquiry before the next process was described. The three numbers preceding each listed process of science identify the Part, page, and activity where that process was used (e.g. 2-9-1 refers to Part 2, page 9, activity 1 as numbered in the printed program materials). Some processes of science listed are preceded by only the Part number as they do not specifically fall on a distinct page or within a given activity. (For a scope and sequence of processes incorporated, see Appendix B.)

Summary

In summary, this investigator's analysis of printed materials indicated that the writer of the materials appeared to have developed two important basic topics of physics in some depth, mechanics and wave motion. He also incorportaed the processes of science throughout by having the student interact with materials and ideas in an investigative approach to learn and expand science concepts.

Characteristics of the Sample

This section contains findings concerning preference for Myers-Briggs Type, intelligence quotients, selected tests of the Iowa Tests of Educational Development, sex, and pre-test and post-test sample variance.

Preference for Myers-Briggs Type

The data obtained by the administration of the Myers-Briggs Type Indicator (Myers 1962) during the first week of school in the fall are shown in Table 3, p. 49. The forty-eight students in the sample were approximately evenly divided on the preference for extraversion or introversion. The preference for sensing or intuition as a way of interacting with the environment was largely for intuition with seventy-five percent of the students indicating that they preferred to come to conclusions in this manner. The choice of thinking or feeling as the kind of behavior individuals in the sample tended to prefer using was approximately fifty-six percent for feeling and forty-four percent for thinking. This difference was assumed not

TABLE 3

PERCENTAGE OF COLUMBUS SAMPLE FOUND IN SIXTEEN TYPE GROUPS AND INDIVIDUAL TYPES

ISTJ 2.1	ISFJ 2.1	INFJ 0.0	INTJ 8.3
ISTP 2.1	ISFP 6.2	INFP 16.7	INTP 10.4
ESTP 6.2	ESFP 2.1	ENFP 27.1	ENTP 8.3
ESTJ 4.2	ESFJ 0.0	ENFJ 2.1	ENTJ 2.1

Index	Preference	Percentage
E	Extraversion	52.1
I	Introversion	47.9
S	Sensing	25.0
N	Intuition	75.0
T	Thinking	43.7
F	Feeling	56.3
J	Judgment	20.8
P	Perception	79.2

N=48

great enough to reflect that a significant portion of the sample preferred arriving at a judgment in either specific manner. Approximately seventy-nine percent of the sample preferred to deal with the environment through perception and only twenty-one percent through judgment. The large majority thus relied on intuition and perception for dealing with their environment. These major preferences resulted in placing approximately sixty-two percent of the population in the INFP, INTP, ENFP, and ENTP type groups.

Intelligence quotients

The intelligence quotients of the sample ranged from 85 to 140. The median of the intelligence quotients was 117 and the mean 116. The intelligence quotient of one student was not available. All of the sample were seniors. The mean intelligence quotient of the senior class at the school was 112. Eighteen or 38 percent, of the 47 students for whom intelligence quotients were available had intelligence quotients of 112 or less. From these figures it was apparent that students of average and below mental ability appeared to enroll in the program in substantial numbers. (For a listing of intelligence quotients, see Table 4, p. 51 and means on Table 5, p. 53.)

Iowa Tests of Educational Development

The Iowa Tests of Educational Development (Lindquist 1960) were administered to all seniors during the first part of the fall semester. Standard scores on the test, Background in the Natural Sciences, ranged from 5 to 29 with a mean of 22.5. This was a range in percentile rank of 1 to 98 and an approximate average of 69 on

TABLE 4

SAMPLE CHARACTERISTICS 1969-70

Student					ITED Standard Score			
Number	School	Sex	Class	IQ	Sci Bkgrd	Sci Rdg	Math	Comp
01	Columbus	M	Sr	125	26	11	28	19
02	Columbus	M	Sr	110	22	28	27	28
03	Columbus	M	Sr	85	21	19	22	17
04	Columbus	M	Sr	125	24	29	28	28
05	Columbus	M	Sr	98	23	24	09	22
06	Columbus	F	Sr	128	23	31	30	34
07	Columbus	M	Sr	117	21	29	30	27
08	Columbus	M	Sr	110	25	24	14	22
09	Columbus	M	Sr	93	05	01	13	04
10	Columbus	M	Sr	112	25	31	30	31
11	Columbus	M	Sr	118	26	31	28	31
12	Columbus	M	Sr	117	20	27	23	26
13	Columbus	M	Sr	98	24	28	22	25
14	Columbus	M	Sr	125	25	34	30	34
15	Columbus	M	Sr	114	20	17	18	19
16	Columbus	M	Sr	121	22	26	30	27
17	Columbus	M	Sr	112	23	28	21	24
18	Columbus	M	Sr	109	22	21	21	20
19	Columbus	M	Sr	135	26	32	32	33
20	Columbus	M	Sr	112	25	31	27	29
21	Columbus	F	Sr		23	29	26	31
22	Columbus	M	Sr	115	21	23	34	31
23	Columbus	M	Sr	125	26	32	31	33

TABLE 4, continued

Student					ITED Standard Score			
Number	School	Sex	Class	IQ	Sci Bkgrd	Sci Rdg	Math	Comp
24	Columbus	M	Sr	114	23	29	26	30
25	Columbus	M	Sr	122	27	30	34	31
26	Columbus	M	Sr	108	17	17	25	17
27	Columbus	M	Sr	118	25	31	25	31
28	Columbus	M	Sr	109	17	25	32	25
29	Columbus	M	Sr	121	24	31	29	32
30	Columbus	F	Sr	127	26	31	30	35
31	Columbus[a]	M	Sr	126	25	29	26	30
32	Columbus	M	Sr	110	11	27	17	21
33	Columbus	M	Sr	122	28	29	25	32
34	Columbus	M	Sr	140	29	33	32	36
35	Columbus	M	Sr	108	14	24	26	23
36	Columbus	M	Sr	128	26	32	25	34
37	Columbus	F	Sr	119	24	32	24	30
38	Columbus	F	Sr	121	22	28	30	29
39	Columbus	M	Sr	111	28	33	25	32
40	Columbus	M	Sr	120	28	34	31	36
41	Columbus	M	Sr	94	24	26	22	22
42	Columbus	M	Sr	127	22	30	30	31
43	Columbus	F	Sr	116	23	26	26	26
44	Columbus	M	Sr	110	23	28	18	28
45	Columbus	F	Sr	114	24	30	25	30
46	Columbus	M	Sr	132	27	32	24	35
47	Columbus	M	Sr	102	15	21	18	20
48	Columbus	M	Sr	130	23	32	34	34

TABLE 5

SUMMATION OF SAMPLE CHARACTERISTICS

Student					Mean Score			
Number	School	Sex	Class	IQ	Sci Bkgrd	Sci Rdg	Math	Comp
n=41	Columbus	M		116	23	27	25	27
n=7	Columbus	F		121	23	30	27	31
n=48	Columbus	M+F		116	23	27	26	28

Iowa norms. The range in standard scores for the test, Reading in the Natural Sciences, was 1 to 34 with a mean of 25.8. The range of percentile rank was 1 to 99 with an approximate average of 80 on Iowa norms. The Quantitative Thinking test scores ranged from 9 to 34 with a mean of 24.6. Percentile ranks ranged from 10 to 99 with an approximate average of 80 on Iowa norms. Composite scores ranged from 4 to 38 with a mean of 26.2. Percentile ranks ranged from 3 to 99 with an approximate average of 84 on Iowa norms. (For a listing of ITED standard scores, see Table 4, p. 51 and means on Table 5, p. 53.)

Sex

The forty-eight students that enrolled in physics included 7 girls and 41 boys. This percentage of girls enrolling appeared to be low compared to other data of physics enrollments (Simon and Grant 1968). Thus there did not appear to be any evidence that this physics program was increasing the percentage of students taking physics by appealing more strongly to high school girls. (For a designation of sex, see Table 4, p. 51 and means on Table 5, p. 53.)

Summary

In summary, this investigator found that individuals in the sample were rather evenly divided between extraversion and introversion and between thinking and feeling in dealing with the environment. However, 75 percent chose intuition to 25 percent for sensing and 79 percent chose perception to 21 percent for judgment in dealing with their environment.

The enrollment of girls in the physics program indicated the program was not popular with them.

Iowa Tests of Educational Development percentile rankings based on Iowa norms ranged from a low of 1 to 10 to a high of 98 or 99 on the three tests dealing with science and quantitative thinking as well as on the composite. Group average percentile ranks ranged from 69 to 84 on the three tests and the composite. Although group averages were good, almost the entire range of percentile ranks was present. Pre-test and post-test groups were found not significantly different on characteristics related to success in the program.

Performance Characteristics

Several dependent variables were studied utilizing multiple regression to determine what independent variables predicted positive scores on them. The dependent variables, never treated as independent variables, were positive scores on physics tests or selected items from several physics tests.

Scores on Unit I Test

Table 6, p. 56 presents an analysis of variables related to the Score on Unit I Test. The order in which independent variables emerged was Quantitative Thinking (ITED), weeks spent on Unit I, and total materials Parts completed. The amount of variance accounted for by each was 33.19, 8.53, and 1.61 percent respectively. The direction of the relationship was positive for Quantitative Thinking, negative for the weeks spent on Unit I, and positive for the total materials

Parts completed. Students with high quantitative thinking abilities scored better on this Unit Test. It may be that this ability allowed them to work more rapidly through Unit I and caused the inverse relationship between time spent and the Score on Unit I Test, which covered Parts that were basically quantitative.

TABLE 6

MULTIPLE REGRESSION WITH SCORE ON UNIT I TEST AS DEPENDENT VARIABLE

Step Number	Independent Variable Entered-Removed	R	RSQ	Increase in RSQ	F Value to Enter or Remove	Relationship
1	Quantitative Thinking (ITED)	0.5761	0.3319	0.3319	19.8032	+
2	Weeks on Unit I	0.6459	0.4171	0.0853	[illegible]	-
3	Parts Completed	0.6583	0.4334	0.0162	[illegible]	-

Scores on Unit II Test

Table 7, p. 57 presents an analysis of variables related to Score on Unit II Test. The order in which independent variables emerged was Quantitative Thinking (ITED), total materials Parts completed, and intelligence quotient. The amount of variance accounted for by each was 41.56, 18.85, and 0.90 percent respectively. The direction of relationship was positive in all cases. Scores on Unit II Test were more strongly predicted by Quantitative Thinking than on Unit I where the variance accounted for was 33.19 percent.

TABLE 7

MULTIPLE REGRESSION WITH SCORE ON UNIT II TEST AS DEPENDENT VARIABLE

Step Number	Independent Variable Entered-Removed	R	RSQ	Increase in RSQ	F Value to Enter or Remove	Relationship
1	Quantitative Thinking (ITED)	0.6447	0.4156	0.4156	28.4436	-
2	Parts Completed	0.7772	0.6041	0.1885	18.5705	-
3	I.Q.	0.7830	0.6131	0.0090	0.8813	-

Scores on Unit III or IV Tests

Multiple regression was not computed for these Unit Tests because the number of Columbus students completing these Units was assumed insufficient. One of the causes of this limited completion was that learning hierarchies were not sequentially arranged.

Part Score

The Part Score was the number of items correctly answered that appeared on Part Tests first and later appeared on the Final Test. There was one of these items on each Part Test.

Table 8, p. 58 presents the analysis of variables related to the Part Score. The order in which independent variables emerged was total materials Parts completed, Quantitative Thinking (ITED), and the weeks spent on Unit I. The amount of variance accounted for by each was 82.71, 5.75, and 1.68 percent respectively. Materials Parts completed and Quantitative Thinking were positively related to the Part Score. Weeks spent on Unit I was negatively related.

Students completing more Parts of the materials took more appropriate items because they had completed more Part Tests and this was probably a determining factor in their getting more items correct. Thus the variance accounted for of 82.71 percent by Parts completed was not surprising. This high variance accounted for by Parts completed shielded the emergence of Quantitative thinking (F=19.4241).

TABLE 8

MULTIPLE REGRESSION WITH PART SCORE AS DEPENDENT VARIABLE

Step Number	Independent Variable Entered-Removed	R	RSQ	Increase in RSQ	F Value to Enter or Remove	Relationship
1	Parts Completed	0.9095	0.8271	0.8271	191.3943	-
2	Quantitative Thinking (ITED)	0.9495	0.8846	0.0575	19.4241	-
3	Weeks on Unit I	0.9499	0.9024	0.0178	[illegible]	-

Final Test Score

Table 9, p. 59 presents an analysis of variables related to the Final Test Score. The order in which independent variables emerged was total materials Parts completed, Quantitative Thinking (ITED), and weeks spent on Unit I. The amount of variance accounted for by each was 52.26, 18.85, and 1.47 percent respectively. The relationship was positive for Parts completed and Quantitative Thinking. The weeks spent on Unit I was negatively related. Students completing more Parts took more appropriate items, and got more of them correct. Quantitative Thinking was a significant predictor of the Final Score (F=25.4402).

TABLE 9

MULTIPLE REGRESSION WITH FINAL TEST SCORE AS DEPENDENT VARIABLE

Step Number	Independent Variable Entered-Removed	R	RSQ	Increase in RSQ	F Value to Enter or Remove	Relationship
1	Parts Completed	0.7229	0.5226	0.5226	43.7834	+
2	Quantitative Thinking (ITED)	0.8433	0.7111	0.1885	25.4482	+
3	Weeks on Unit I	0.8519	0.7258	0.0147	2.0331	-

Equated Final Test Score

The Equated Final Test Score was determined by taking the number of items answered correctly on the Final Test, dividing it by the items to be answered based on the number of materials Parts completed, and multiplying the resultant quotient by thirty-six which was the total number of test items. Students had been instructed to answer as many items as they had completed Parts of the materials and only that number of items was corrected. The Equated Final Test Score was an indicator of how well the student performed on test items covering Parts completed.

Table 10, p. 60 presents an analysis of variables related to the Equated Final Test Score. The order in which independent variables emerged was Quantitative Thinking (ITED), Parts completed, and weeks on Unit I. The amount of variance accounted for by each was 44.02, 1.70, and 3.26 percent respectively. Quantitative Thinking was positively related and Parts completed and weeks on Unit I were negatively related. Quantitative Thinking accounted for more variance here than it did for Score on Units I or II Tests. Quantitative Thinking accounted for a variance of the Score on Unit I Test of 33.19 percent, Score on Unit II Test of 41.56 percent, and the Equated Final Test Score of 44.02 percent.

TABLE 10

MULTIPLE REGRESSION WITH EQUATED FINAL TEST SCORE AS DEPENDENT VARIABLE

Step Number	Independent Variable Entered-Removed	R	RSQ	Increase in RSQ	F Value to Enter or Remove	Relationship
1	Quantitative Thinking (ITED)	0.6635	0.4402	0.4402	31.4523	-
2	Parts Completed	0.6755	0.4563	0.0160	1.1511	-
3	Weeks on Unit I	0.6992	0.4889	0.0326	2.4243	-

Equated PSSC Score

The Equated PSSC Score was determined by taking the number of items answered correctly, dividing it by the items to be answered based on the materials Parts completed, and multiplying the quotient by eighty. Items were sequenced to follow the materials and the investigator determined the cut-off point, based on materials Parts each had completed, beyond which items were not counted even though they might have been answered.

Table 11, p. 61 presents an analysis of variables related to the Equated PSSC Score. The order in which independent variables emerged was Reading in the Natural Sciences (ITED), weeks spent on Unit I, and Parts completed. The amount of variance accounted for by each was 21.37, 11.79, and 2.28 percent respectively. The direction of relationship was positive for Reading in the Natural Sciences, negative for weeks spent on Unit I, and positive for Parts completed. The PSSC Test did not require as much quantitative thinking as did the evaluation instruments developed by the investigator. Analysis also indicate that the completion of more Parts of the physics self-pacing program improved scores.

TABLE 11

MULTIPLE REGRESSION WITH EQUATED PSSC SCORE AS DEPENDENT VARIABLE

Step Number	Independent Variable Entered-Removed	R	RSQ	Increase in RSQ	F Value to Enter or Remove	Relationship
1	Reading in Natural Sciences (ITED)	0.4622	0.2137	0.2137	10.8686	+
2	Weeks on Unit I	0.5758	0.3315	0.1179	6.8761	-
3	Parts Completed	0.5953	0.3544	0.0228	1.3442	+

Summary

It was apparent that satisfactory performance in this course required quantitative thinking abilities. Quantitative Thinking accounted for 33 percent of the variance for Score on Unit I Test, 41.6 percent for Score on Unit II Test, and 44 percent for the Equated Final Test Score. This constant increase indicated that quantitative thinking became a more dominant factor in accounting for success in the program as students progressed further through the materials. It also indicated the material did not develop needed skills. The intelligent quotient was not as important in determining test scores. A summary of significant variables related to success is on Table 12, p. 62.

TABLE 12

VARIABLES RELATED TO SUCCESS

Independent Variable	Dependent Variable					
	Unit I Score	Unit II Score	* Parts Score	Final Test Score	** Equated Final Score	*** Equated PSSC Score
Intelligence Quotient						
Background in the Natural Sciences						
Reading in the Natural Sciences						1 R=.46
Quantitative Thinking	1 R=.58	1 R=.64	1+2 R=.94	1+2 R=.84	1 R=.66	
Composite ITED						
Weeks Spent on Unit I	1+2 R=.65					1+2 R=.58
Weeks Spent on Unit II						
Parts of Course Completed		1+2 R=.78	1 R=.91	1 R=.72	1+2 R=.68	

*Parts Score = items correct on Part tests that appeared on Final Test

$$\text{**Equated Final Score} = \frac{\text{items taken correct}}{\text{items to be taken}} \times 36$$

$$\text{***Equated PSSC Score} = \frac{\text{items taken correct}}{\text{items to be taken}} \times 80$$

N = 42

Learning Hierarchies

The materials were examined to determine if learning hierarchies existed. This was attempted because examination of the materials resulted in the investigator concluding that the materials were primarily concept oriented and required considerable skill in quantitative thinking.

The procedure used to determine if learning hierarchies existed was to ascertain what concept or concepts were included in each test item from Part Tests 2 through 23, (Bloom's Taxonomy 1956) how test items correlated, and success on specific test items. This information was then used to develop patterns of relationships among items.

Concepts in test items and their selection

The items were constructed on the basis of an analysis of concepts found in the materials. They were categorized as to concept or concepts included in each item utilizing the concept areas listed on the scope and sequence chart in Appendix A, p. 10 . The items were also constructed to utilize the models to the extent that they had been developed in the materials in that Part or previous Parts.

Concepts in test items for Parts 2 through 23 were selected for analysis. Item selection was terminated at this point because an established level of completion of Parts had been set at seventy-five percent and Part 23 was the last one to meet this criteria.

The majority of test items were judged to evaluate the attainment of more than one concept. An item might deal with velocity and translational motion; velocity and rotational motion; translational motion, velocity, and force; force and acceleration; falling bodies and acceleration; or other combinations. Thus a test item might be considered for inclusion in one or more hierarchies. (For the concept designation of each test item, see Table 14, p. 66.)

The test item type

The test item type determination was based on Bloom's Taxonomy (1956). It was categorized as Type I if it involved knowledge or concepts. These were considered the lowest cognitive levels. If the learner was required to operate at the application or analysis levels, it was categorized as Type II. Test items were categorized as Type III if they called for behavior that required synthesis or evaluation. Each test item was typed at the highest level of behavior required in answering the item as judged by the investigator. (For the type designation of items, see Table 14, p. 66.)

Correlation of test items

A 280 by 280 correlation matrix was run on the computer. Correlations significant at the .05 level were determined and selected. Those items significantly correlated with a particular item were listed on separate sheets of paper.

Analysis for item relationships

Test items of a given concept were selected for analysis. They were placed in three categories based on type designation. Those of Type III were checked for significant correlation with other items

BEST COPY AVAILABLE

TABLE 13

KEY TO TEST ITEM NUMBERING

Number	Part	Item
1	2	1
2	2	2
3	2	3
4	2	4
5	2	5
6	2	6
7	2	7
8	2	8
9	2	9
10	2	10
11	2	11
12	2	12
13	2	1
14	3	2
15	3	3
16	3	4
17	3	5
18	3	6
19	3	7
20	3	8
21	3	9
22	3	10
23	3	11
24	3	12
25	4	1
26	4	2
27	4	3
28	4	4
29	4	5
30	4	6
31	4	7
32	4	8
33	4	9
34	4	10
35	4	11
36	4	12
37	5	1
38	5	2
39	5	3
40	5	4
41	5	5
42	5	6
43	5	7
44	5	8
45	5	9
46	5	10
47	5	11
48	5	12
49	6	1
50	6	2
51	6	3
52	6	4
53	6	5
54	6	6
55	6	7
56	6	8
57	6	9
58	6	10
59	6	11
60	6	12
61	7	1
62	7	2
63	7	3
64	7	4
65	7	5
66	7	6
67	7	7
68	7	8
69	7	9
70	7	10
71	7	11
72	7	12
73	8	1
74	8	2
75	8	3
76	8	4
77	8	5
78	8	6
79	8	7
80	8	8
81	8	9
82	8	10
83	8	11
84	8	12
85	9	1
86	9	2
87	9	3
88	9	4
89	9	5
90	9	6
91	9	7
92	9	8
93	9	9
94	9	10
95	9	11
96	9	12
97	10	1
98	10	2
99	10	3
100	10	4
101	10	5
102	10	6
103	10	7
104	10	8
105	10	9
106	10	10
107	10	11
108	10	12
109	11	1
110	11	2
111	11	3
112	11	4
113	11	5
114	11	6
115	11	7
116	11	8
117	11	9
118	11	10
119	11	11
120	11	12
121	12	1
122	12	2
123	12	3
124	12	4
125	12	5
126	12	6
127	12	7
128	12	8
129	12	9
130	12	10
131	12	11
132	12	12
133	13	1
134	13	2
135	13	3
136	13	4
137	13	5
138	13	6
139	13	7
140	13	8
141	13	9
142	13	10
143	13	11
144	13	12
145	14	1
146	14	2
147	14	3
148	14	4
149	14	5
150	14	6
151	15	1
152	15	2
153	15	3
154	15	4
155	15	5
156	15	6
157	15	7
158	15	8
159	15	9
160	15	10
161	15	11
162	15	12
163	16	1
164	16	2
165	16	3
166	16	4
167	16	5
168	16	6
169	16	7
170	16	8
171	16	9
172	16	10
173	16	11
174	16	12
175	17	1
176	17	2
177	17	3
178	17	4
179	17	5
180	17	6
181	17	7
182	17	8
183	17	9
184	17	10
185	17	11
186	17	12
187	18	1
188	18	2
189	18	3
190	18	4
191	18	5
192	18	6
193	18	7
194	18	8
195	18	9
196	18	10
197	18	11
198	18	12
199	19	1
200	19	2
201	19	3
202	19	4
203	19	5
204	19	6
205	19	7
206	19	8
207	19	9
208	19	10
209	19	11
210	19	12
211	20	1
212	20	2
213	20	3
214	20	4
215	20	5
216	20	6
217	20	7
218	20	8
219	20	9
220	20	10
221	20	11
222	20	12
223	21	1
224	21	2
225	21	3
226	21	4
227	21	5
228	21	6
229	21	7
230	21	8
231	21	9
232	21	10
233	21	11
234	21	12
235	22	1
236	22	2
237	22	3
238	22	4
239	22	5
240	22	6
241	22	7
242	22	8
243	22	9
244	22	10
245	22	11
246	22	12
247	23	1
248	23	2
249	23	3
250	23	4
251	23	5
252	23	6
253	23	7
254	23	8
255	23	9
256	23	10
257	23	11
258	23	12
259	F	1
260	i	2
261	n	3
262	a	4
263	l	5
264		6
265		7
266		8
267		9
268		10
269		11
270		12
271		13
272		14
273		15
274		16
275		17
276		18
277		19
278		20
279		21
280		22

BEST COPY AVAILABLE

TABLE 14

TEST ITEM DATA

*Item	**Type			***Content							****Model				
	I	II	III	TM	RM	Ve	Fo	Ac	RB	Os	Gr	Se	DT	Di	De
1	x					x					x				
2	x			x		x					x				
3	x			x		x					x	x			
4	x			x		x					x				
5		x		x		x					x	x			
6	x			x							x	x			
7	x					x					x				
8	x			x		x					x				
9	x			x		x					x	x			
10	x			x		x					x				
11		x		x		x					x	x			
12		x		x		x					x				
13	x			x		x					x	x			
14	x			x		x					x				
15	x			x		x					x				
16	x			x		x					x				
17		x									x	x			
18	x										x				
19		x		x		x					x	x			
20	x			x							x	x			
21		x		x		x					x				
22		x		x		x					x	x			
23		x		x		x					x				
24		x		x		x					x	x			
25	x											x			
26		x										x			
27		x										x		x	
28	x											x		x	
29		x										x		x	
30		x										x			x
31	x											x			
32	x											x			
33		x										x		x	x
34			x									x		x	x
35		x										x		x	x
36		x										x		x	x
37		x		x	x	x						x		x	
38		x		x	x	x						x		x	
39		x			x	x						x			
40			x		x	x						x		x	

*See Table   for a key to test item numbering.

**From Bloom, Taxonomy of Educational Objectives: I (Knowledge and Concepts), II (Application and Analysis), III (Synthesis and Evaluation).

***TM (Translational Motion), RM (Rotational Motion), Ve (Velocity), Fo (Force), Ac (Acceleration), RB (Rolling Bodies), Os (Oscillation.

****Gr (Graph Model), Se (Sentence Model), DT (Data Table Model), Di (Diagram Model), De (Descriptive Model).

BEST COPY AVAILABLE

TABLE 14--Continued

*Item	**Type			***Concept							****Model				
	I	II	III	[illegible]	[illegible]	[illegible]	[illegible]	Ac	[illegible]	Cs	[illegible]	Se	[illegible]	[illegible]	[illegible]
41	x				x	x						x		x	
42	x											x			x
43		x										x			x
44		x			x							x			x
45	x				x							x			x
46	x				x							x			x
47	x				x							x			x
48	x				x							x			x
49		x		x		x						x		x	
50		x		x		x						x		x	
51		x		x		x						x		x	
52			x	x		x						x		x	
53	x			x	x							x		x	
54		x		x	x	x					x	x		x	
55	x			x	x							x		x	
56		x		x	x							x		x	
57		x		x	x							x		x	
58		x		x	x							x		x	
59			x	x	x							x		x	
60			x	x	x							x		x	
61		x				x						x		x	
62	x					x						x		x	
63	x			x		x						x		x	
64		x										x		x	
65		x										x		x	
66		x										x		x	
67	x											x		x	
68		x										x		x	
69		x				x						x			
70	x											x			
71	x							x				x			
72	x							x				x			
73			x	x		x	x					x		x	
74			x	x								x		x	
75	x			x								x			
76	x			x		x						x			
77		x		x		x	x					x			
78		x		x		x	x					x			
79		x		x		x	x					x			
80		x		x		x						x			
81	x			x								x			
82	x											x			
83		x		x								x		x	
84		x		x								x		x	
85		x		x		x						x			
86		x				x						x			
87	x			x		x						x			
88								x				x			
89	x										x	x			
90		x									x	x			
91		x									x	x			

TABLE 14--continued

Film	***Type					***Concept					***Model				
	I	II	III	IV	V	Vo	Fo	Ac	Pb	Co	Cr	Sc	[illegible]	Hi	Ne
92	x			x								x			
93		x										x			
94		x										x			
95		x										x			
96		x										x			
97	x							x			x	x			
98								x			x	x			
99	x							x			x	x			
100		x				x	x	x				x		x	
101		x					x	x				x		x	
102		x					x	x				x		x	
103		x					x	x				x		x	
104			x				x					x		x	
105	x					x					x	x			
106	x			x		x		x			x	x			
107	x						x					x		x	
108		x					x					x		x	
109		x			x			x				x		x	
110		x			x		x					x		x	
111		x			x		x					x		x	
112		x			x										
113		x		x		x						x		x	
114		x			x		x					x			
115		x					x					x		x	
116		x					x					x		x	
117		x		x	x		x					x		x	
118		x		x	x	x	x					x		x	
119	x						x					x		x	
120		x		x			x					x		x	
121		x		x		x		x				x		x	
122	x							x				x		x	
123		x		x				x				x		x	
124	x			x								x		x	
125		x				x		x				x			
126			x			x		x			x	x			
127			x			x		x			x	x			
128		x		x				x				x			
129		x		x		x		x				x			
130		x				x		x				x			
131		x				x		x				x			
132			x	x		x		x				x			
133	x			x	x							x			x
134	x			x	x							x			x
135	x			x	x							x			x
136	x			x	x							x			x
137	x			x	x							x			x
138	x			x	x							x			x
139	x			x	x							x		x	
140		x		x	x			x				x		x	
141		x			x			x				x		x	
142		x			x			x				x		x	

TABLE 14--continued

*Item	**Type			***Concept							****Model				
	I	II	III	[illegible]	[illegible]	[illegible]	[illegible]	Ac	[illegible]	Cs	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
143		x			x	x		x				x		x	
144		x			x			x				x		x	
145		x						x	x			x			
146	x							x	x			x		x	
147		x						x	x			x	x		
148	x							x	x			x			
149	x							x	x			x			
150	x							x	x			x			
151		x		x				x	x			x			
152		x		x				x	x			x		x	x
153		x		x				x	x			x		x	x
154		x			x			x	x			x		x	x
155		x			x			x	x			x		x	x
156		x		x	x			x	x			x		x	x
157			x	x	x			x	x			x			
158		x		x	x			x	x			x			
159		x		x	x			x	x			x			
160		x		x	x			x	x			x			
161		x		x	x			x	x			x			
162			x	x	x			x	x			x			
163			x				x					x			
164	x						x					x			
165	x						x	x				x			
166	x						x					x			
167	x						x					x			
168	x						x	x				x			
169	x						x					x			
170	x						x					x			
171	x						x					x			
172		x					x	x				x			
173	x						x					x			
174	x						x					x			
175	x						x	x				x			
176	x						x					x			
177	x						x					x			
178			x					x							x
179		x					x	x				x		x	
180	x						x					x		x	
181		x					x					x		x	
182		x					x					x			
183		x					x	x				x			
184	x						x	x				x			
185		x					x					x			
186			x				x					x		x	
187	x					x				x	x	x			
188	x									x		x		x	
189			x					x		x		x		x	
190		x						x		x		x		x	
191										x		x		x	
192		x				x				x		x		x	
193		x						x		x		x		x	

BEST COPY AVAILABLE

TABLE 14--continued

*Item	**Type			***Concept							****Model				
	I	II	III	[illegible]	[illegible]	Va	Fr	Xd	[illegible]	Co	Or	Se	[illegible]	Di	[illegible]
194			x							x				x	
195			x							x				x	
196	x									x		x		x	
197		x								x		x		x	
198		x								x		x			x
199	x							x		x		x			
200	x					x				x		x			
201	x									x				x	
202		x				x				x		x		x	
203		x								x		x		x	
204		x								x					
205		x						x		x		x		x	
206	x									x				x	
207		x				x				x		x		x	
208		x				x				x		x		x	
209		x								x				x	
210	x							x		x		x		x	
211	x						x					x	x		
212		x		x			x					x	x		
213		x		x			x					x	x		
214	x						x			x					
215	x						x			x		x			
216	x									x		x			
217	x									x		x			
218		x						x		x		x			x
219	x						x			x		x			
220		x					x	x		x		x			
221	x									x		x		x	
222	x									x		x		x	
223		x		x								x		x	
224		x				x						x		x	
225		x				x						x		x	
226		x					x					x		x	
227	x			x		x		x	x			x		x	
228			x			x								x	
229		x		x		x		x	x					x	
230			x	x		x	x	x	x			x		x	
231		x				x	x	x				x			
232		x					x					x			
233		x					x	x				x			
234		x					x					x			
235		x					x	x				x			
236		x		x			x	x			x	x			
237		x		x			x					x			
238		x			x		x					x		x	
239		x		x	x	x	x					x		x	
240		x		x	x	x	x					x		x	
241		x		x		x	x	x						x	
242		x				x	x							x	
243		x					x					x		x	
244		x		x	x		x					x		x	

TABLE 14--continued

*Item	**Type			***Concept							***Model				
	I	II	III	[illegible]	[illegible]	[illegible]	[illegible]	Ac	[illegible]	Ca	[illegible]	Sa	[illegible]	Di	[illegible]
245		x		x	x		x					x			
246			x	x			x					x		x	
247	x					x		x		x		x		x	
248	x			x			x	x		x		x		x	
249	x					x		x		x		x		x	
250	x						x	x		x		x		x	
251		x		x		x	x	x		x		x		x	
252		x				x	x	x		x		x		x	
253	x			x			x			x		x		x	
254	x			x		x	x			x		x		x	
255	x									x		x		x	
256	x					x	x			x		x		x	
257	x			x		x		x				x		x	
258	x			x		x						x		x	
259	x			x		x					x	x			
260		x		x		x					x	x			
261	x											x			
262		x		x	x	x						x		x	
263		x		x		x						x		x	
264		x										x		x	
265	x			x								x			
266		x									x	x			
267	x							x			x				
268		x			x			x				x		x	
269					x			x				x		x	
270	x			x	x							x		x	
271	x							x	x			x			
272		x		x				x	x			x			
273	x						x								
274	x						x					x		x	
275	x					x				x		x		x	
276		x				x				x		x		x	
277		x					x	x		x		x			
278			x			x								x	
279		x					x	x				x			
280	x					x		x		x		x		x	

of that Type. A cluster of items was selected from this group based on criteria that each one included correlated significantly with half or more of the other items in the selected cluster. They formed Cluster III for a specific concept.

Type II items were then checked for significant correlation with one or more items within Type II. An item was dropped from the group if no significant correlations existed. Correlations were then checked between Type II items and those from Cluster III. If a Type II item correlated significantly with half or more of the Cluster III items it was included in Cluster II for the concept.

Type I items were then checked for significant correlation with one or more items within the Type I items. An item was dropped from the group if no correlations existed. Correlations were then checked between group I items and Cluster II items. The item was selected for Cluster I if it correlated significantly with half or more of the Cluster II items for that specific concept.

Cluster III items were also checked for direct linkage to group I items. When a group I item correlated directly with half or more of the Cluster III items it was also included in a separate Cluster I grouping.

Determining average cluster item difficulty

The next step in hierarchy analysis was to determine the average item difficulty of the cluster. Item difficulty used was based on the number of students who had attempted the item and who successfully completed it.

Interpreting cluster relationships

The average item difficulty in a cluster was then compared with the similar characteristic of other clusters. An increase in average cluster item difficulty from Cluster I to II and II to III was interpreted to suggest a learning hierarchy. A learning hierarchy existed when lower type items predicted success on higher type items.

Established hierarchies and analysis

Hierarchies were found for translational and rotational motion, velocity and falling bodies, force, acceleration, and oscillation. They are presented in Tables 15 through 19, pp. 74-78.

An analysis of the test item numbering in each cluster indicated, that although hierarchies existed, the sequencing from lower orders of behavior required to higher levels of behavior was not orderly for a concept.

An examination of specific items in the clusters revealed many dealing with quantitative thinking. Thus it was concluded that there was substantial loading with quantitative thinking in the materials. Most of the test items from early Parts related to success on later test items involved mathematical abilities.

A comparison of correlations between Cluster III items of the different concepts was made to determine if performance on test items was dependent on student ability or concept development. If the majority of Cluster III test items correlated significantly with each other, performance was considered related to student ability. Performance was considered dependent on concept development if a

BEST COPY AVAILABLE

TABLE 15

MOTION: TRANSLATIONAL AND ROTATIONAL HIERARCHY

Cluster I

Item Number	Percent Correct	Ratio of Correlation Found
75	92	11/17
139	91	10/17
227	85	10/17
	89%	

Cluster II

Item Number	Percent Correct	Ratio of Correlation Found
12	65	2/4
22	67	3/4
49	90	3/4
50	75	4/4
51	83	4/4
57	81	4/4
111	91	3/4
112	87	2/4
114	79	2/4
141	68	2/4
142	77	2/4
151	89	2/4
239	81	2/4
241	86	3/4
242	83	3/4
243	71	3/4
244	74	3/4
	80%	

Cluster III

Item Number	Percent Correct
52	75
53	[illegible]
212	72
213	81
	70%

14	88	2/4
*75	92	4/4
87	89	2/4
*139	91	3/4
*227	85	3/4
	89%	

*Item common with above cluster

AVAILABLE

TABLE 16

VELOCITY AND FALLING BODIES HIERARCHY

Cluster I

Item Number	Percent Correct	Ratio of Correlation Found
227	85	8/15
254	63	8/15
	74%	

Cluster II

Item Number	Percent Correct	Ratio of Correlation Found
72	67	4/5
50	75	4/5
61	73	4/5
78	17	4/5
125	83	4/5
130	74	3/5
143	87	3/5
145	85	3/5
147	85	3/5
152	83	3/5
153	83	3/5
154	79	4/5
155	70	4/5
159	79	4/5
192	76	3/5
	74%	

Cluster III

Item Number	Percent Correct
73	67
126	51
127	51
157	61
152	68
	60%

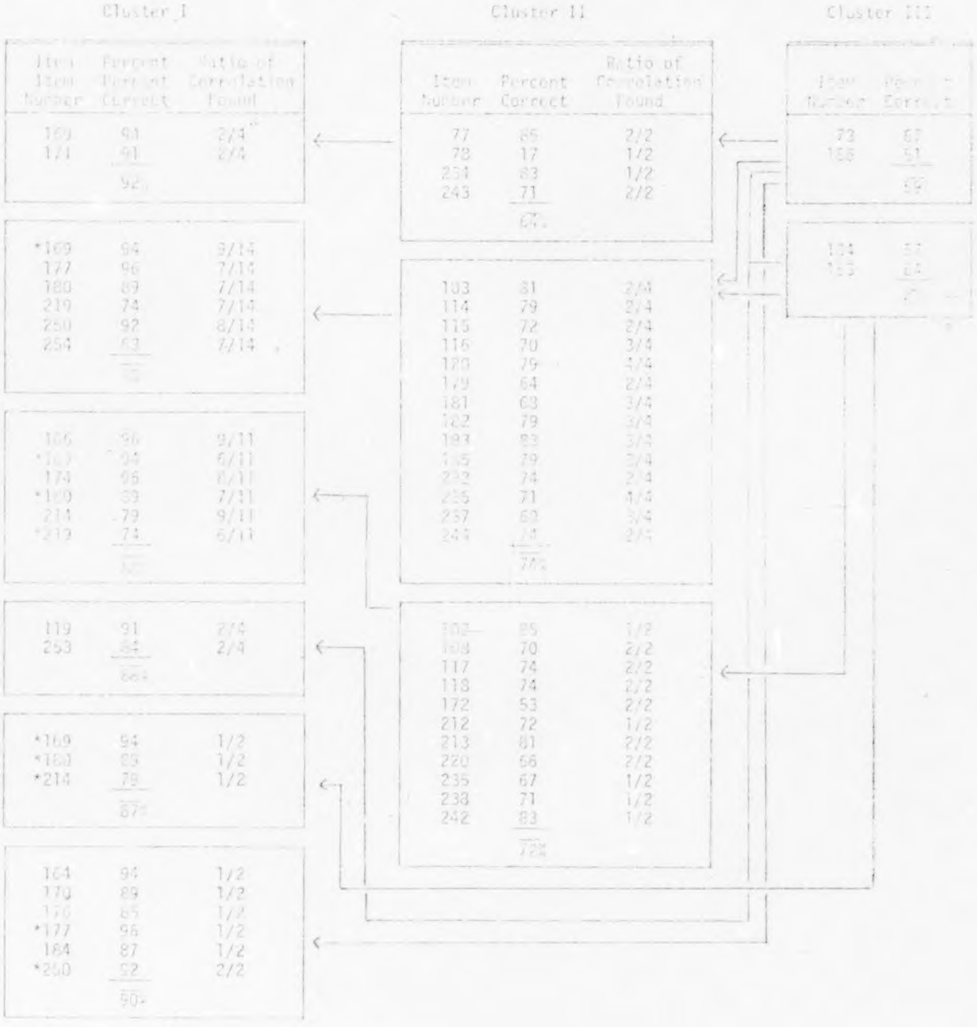
*227	85	3/5

*Item common with above cluster

BEST COPY AVAILABLE

TABLE 17

FORCE HIERARCHY



Cluster I

Item Number	Percent Correct	Ratio of Correlation Found
169	91	2/4
171	91	2/4
	92%	

*169	94	9/14
177	96	7/14
180	89	7/14
219	74	7/14
250	92	8/14
254	63	7/14
	[illegible]	

166	96	9/11
*169	94	6/11
174	96	8/11
*180	89	7/11
214	79	9/11
*219	74	6/11
	[illegible]	

119	91	2/4
253	84	2/4
	88%	

*169	94	1/2
*180	89	1/2
*214	79	1/2
	87%	

164	94	1/2
170	89	1/2
176	85	1/2
*177	96	1/2
184	87	1/2
*250	92	2/2
	90%	

Cluster II

Item Number	Percent Correct	Ratio of Correlation Found
77	85	2/2
78	17	1/2
234	83	1/2
243	71	2/2
	[illegible]	

103	81	2/4
114	79	2/4
115	72	2/4
116	70	3/4
170	79	4/4
179	64	2/4
181	68	3/4
182	79	3/4
183	83	3/4
185	79	3/4
232	74	2/4
236	71	4/4
237	69	3/4
244	74	2/4
	74%	

102	85	1/2
108	70	2/2
117	74	2/2
118	74	2/2
172	53	2/2
212	72	1/2
213	81	2/2
220	56	2/2
235	67	1/2
238	71	1/2
242	83	1/2
	72%	

Cluster III

Item Number	Percent Correct
73	67
168	51
	59

104	53
163	64
	[illegible]

*Item common with an above cluster

BEST COPY AVAILABLE

TABLE 18

ACCELERATION HIERARCHY

Cluster I

Item Number	Percent Correct	Ratio of Correlation Found
227	85	13/22

Cluster II

Item Number	Percent Correct	Ratio of Correlation Found
102	85	3/4
109	68	3/4
123	83	2/4
125	83	3/4
128	72	3/4
130	74	4/4
131	74	2/4
141	68	2/4
142	77	3/4
143	87	3/4
144	79	4/4
146	85	3/4
147	85	2/4
151	89	3/4
154	79	2/4
159	79	4/4
183	83	4/4
190	72	3/4
205	57	3/4
218	74	2/4
231	83	4/4
233	85	4/4
	77%	

Cluster III

Item Number	Percent Correct
126	51
127	51
132	[illegible]
189	51
	54%

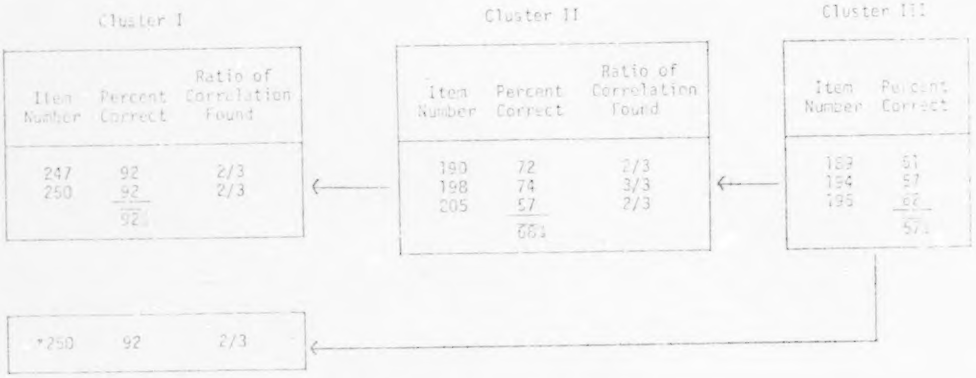
*227	85	4/4
184	87	2/4
247	92	2/4
250	92	2/4
	89%	

*Item common with above cluster

AVAILABLE

TABLE 19

OSCILLATION HIERARCHY



Cluster I

Item Number	Percent Correct	Ratio of Correlation Found
247	92	2/3
250	92	2/3
	92%	

Cluster II

Item Number	Percent Correct	Ratio of Correlation Found
190	72	2/3
198	74	3/3
205	57	2/3
	68%	

Cluster III

Item Number	Percent Correct
183	51
194	57
195	62
	57%

Item Number	Percent Correct	Ratio of Correlation Found
*250	92	2/3

*Item common with above cluster

majority of the Cluster III items did not correlate significantly with each other. Only one of sixteen items correlated significantly at the .05 level with over 50 percent of the other items. The conclusion was drawn that success with the materials was highly dependent on adequate presentation of materials related to each concept. Those students who performed well in a concept area were quite successful in that area, but performance in a specific concept area did not necessarily mean that they performed well in others. Hence, success for students varied considerably. (For a comparison of Cluster III items of different concepts, see Table 20, p. 80.)

Summary

This section described the process of determining whether learning hierarchies existed in the materials. Learning hierarchies established for translational and rotational motion, velocity and falling bodies, force, acceleration, and oscillation were presented. Learning hierarchies were not found to be developed sequentially in the materials. The concept hierarchies were found highly loaded with quantitative thinking abilities. Success with materials was found highly dependent on adequate orderly concept development.

Analysis of Hypotheses

This section contains a restatement of hypotheses, a statement of total or partial support or rejection based on .05 level of

TABLE 20

CORRELATIONS OF CLUSTER III ITEMS

	Motion: Translation and Rotational				Velocity and Falling Bodies					Force				Acceleration				Oscillati		
	52	59	212	213	*73	*126	*127	157	162	*73	186	104	163	*126	*127	132	*189	*189	194	195
52	X	X	X	X																
59	X	X	X	X		X			X			X		X						
212	X	X	X	X		X						X		X		X			X	
213	X	X	X	X		X						X	X	X						
*73					X	X	X	X	X	X	X			X	X		X	X	X	
*126		X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	
*127					X		X			X	X			X	X	X	X	X		
157					X	X		X	X	X				X						
162		X			X	X		X	X	X	X			X						
*73					X	X	X	X	X	X	X			X	X			X		
186					X	X	X		X	X	X				X		X	X	X	
104		X	X	X		X						X	X			X				
163				X					X			X	X							
*126		X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X		
*127					X	X	X			X	X			X	X	X	X	X		
132			X			X	X					X		X	X	X	X	X		
*189					X	X	X			X	X			X	X	X	X	X	X	X
*189					X	X	X			X	X			X	X	X	X	X	X	X
194					X	X	X			X	X			X	X		X	X	X	
195							X				X				X		X	X		
** Correlation at .05 level of Significance	3/15	6/15	6/15	6/15	7/15	12/15 ***	7/15	3/15	6/15	7/15	7/15	6/15	2/15	12/15 ***	7/15	5/15	7/15	7/15	8/15	3/15

* Items occurring in two clusters.

** The number of correlations possible was fifteen as items appearing twice were counted only once and correlations with self were not counted.

*** Same item

significance, the data used as a basis for these conclusions, and any additional pertinent information from prior sections of this chapter. The sequencing of hypotheses used here is similar to that in Chapter I. See Table 21, p. 82 for significance levels of correlations.

Hypotheses concerning short and long-term learning

1. There is no significant correlation between the Unit I or II Test Scores of the sample and the Equated Final Test Score.

   Rejected: For Units I and II Test Scores there was a positive significant correlation at the .01 level. Unit I or II Test Scores appeared to predict the degree to which the student would achieve in Parts completed. Multiple regression analysis suggests that quantitative thinking skills are highly required on all.

2. There is no significant correlation between Unit I or II Test Scores of the sample and the score on items of that Unit appearing on the Final Test.

   Rejected: Units I and II Test Scores had positive significant correlations at the .01 level. Those students who performed well on the tests upon completing a unit also did well on selected items from that unit appearing on the Final Test. Performance on tests seemed quite consistent. Those students who learned more from a unit appeared to retain more from that unit.

3. There is no significant correlation between the time in weeks spent on the sample on Units I or II and the Equated Final Test Score.

BEST COPY AVAILABLE

TABLE 21

CORRELATION--LEVELS OF SIGNIFICANCE
(Columbus, 1969-70)

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
ITED	[illegible]	1																																		
	[illegible] Nat Sci	2	.05																																	
	[illegible]	3	.001	.05																																
	[illegible]	4	.001	.01	.001																															
	Comp	5	.001	.01	.001	.001																														
	[illegible]	6																																		
	[illegible]	7																																		
	[illegible]	8							.05																											
Myers-Briggs	[illegible]	9		.01	.05		.05																													
	[illegible]	10	.05				.05																													
	[illegible]	11								.05																										
	[illegible]	12											.001																							
	[illegible]	13																																		
	[illegible] I	14	.05	.01	.05	.01	.01				.05																									
	[illegible] II	15	.001	.05	.01	.001	.001									.001																				
	[illegible] III	16															.05																			
	[illegible] I	17		.05		.05	.05									.01	.01																			
	[illegible] II	18																																		
	[illegible] III	19																.05																		
	[illegible]	20				.05		.05								.01	.01		.001	.001	.001															
	[illegible]	21	.01			.01		.05								.01	.01		.001	.001	.001	.001														
	Partial Score	22	.001		.05	.001	.01	.01								.001	.01	.05	.001	.01		.001	.001													
	Final Score	23	.001	.05	.05	.001	.001									.001	.01		.001			.001	.001	.001												
	Final-Part	24																	.05	.05		.01	.01	.001												
	Score	25	.001	.01	.05	.001	.001									.001	.001		.001			.001	.001	.001	.001											
	Ed Score	26	.01	.05	.05	.001	.01								.05	.01	.01		.05						.001	.001	.001									
	[illegible] Item	27	.05					.05								.05	.001		.001	.05	.001	.001	.001	.001	.001	.05	.001									
PSSC	[illegible] Corr	28	.01	.01	.01	.01	.01					.05				.05	.001		.001	.05		.001	.001	.001	.001		.001	.05	.001							
	Ed Score	29	.01	.01	.01	.05	.01					.05							.01					.05	.01		.01	.05		.001						
	School	30																																		
	F 1-9	31	.01			.001	.05									.01	.01		.05					.01	.001		.001	.001		.01	.05					
	F 10-18	32				.01						.05		.05		.01	.01		.05			.01	.01	.01	.001		.001	.001	.01	.001	.01		.01			
	F 19-27	33	.001	.01	.01	.001	.001				.05					.001	.001		.001	.01		.001	.001	.001	.001		.001	.01	.001	.001	.01		.01	.001		
	F 28-36	34				.01	.05										.01		.01		.01	.001	.001	.001	.001		.001	.05	.001	.001			.05	.05	.001	
	N*		47	48	48	48	48	25	23	12	36	21	27	10	38	47	43	26	47	43	26	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
	Mean*		116	22.8	27.3	25.7	27.6	17.2	26.0	16.5	25.3	20.7	17.2	18.2	26.3	18.7	[illegible]	11.6	11.8	12.8	8.5	26.6	26.6	22.6	20.2	3.4	20.2	27.4	26.4	9.9	30.2		7.4	7.1	4.5	1.3
	Standard Deviation		11.2	4.5	6.2	5.6	6.4	13.1	14.8	12.2	14.6	10.7	11.5	13.6	16.3	6.9	5.7	8.2	2.1	2.3	2.2	5.6	5.6	7.2	6.1	4.1	6.1	5.3	6.9	4.3	9.0		1.5	1.7	2.8	2.0

Rejected: Unit I had a negative significant correlation at the .05 level. Supported: Unit II had no significant correlation. Unit I dealt mainly with quantitative thinking concepts. This significant negative correlation indicated that students who had quantitative thinking abilities before enrolling completed Unit I rapidly and learned physics concepts more completely. Conversly, it could be interpreted to indicate that those students who did not have quantitative thinking concepts did not develop them through the use of Unit I materials and thus developed physics concepts less well.

4. There is no significant correlation between the time in weeks spent by the sample on Units I or II and the score on items of that Unit that appeared on the Final Test.

Rejected: Unit I had a negative significant correlation at the .05 level. Supported: Unit II had no significant correlation. This significant negative correlation for Unit I items also indicated that students who entered with quantitative thinking abilities scored higher on the Final Test while spending less time on Unit I.

5. There is no significant correlation between the total number of materials Parts completed by the sample and the difference between items correct on the Final Test and Part Tests that appeared on both.

Rejected: A negative significant correlation at the .01 level existed. This negative correlation was interpreted to indicate that those students who completed fewer materials Parts retained more of what was initially learned. Two possible reasons for this relationship were contemplated. The possibility that the students who progressed more slowly had more time to reinforce what was learned was considered and also that the slower progressing students might use a different style of learning. It was considered that these two might really be one causal factor--learning style.

6. There is no significant correlation between the total number of materials Parts completed by the sample and the Equated Final Test Score.

Supported: No significant correlation existed. This supported the conclusion that the retention of what was covered was approximately equal for slow and rapid progressing students. Those students who worked more slowly retained proportionately as much from what was completed as those who worked more rapidly. Those that progressed more rapidly learned more and retained what they learned. It was considered quite probable that there might be a difference in styles that accounted for rate of progress.

7. There is no significant correlation between the items correct on the Part Tests by the sample and the same items appearing on the Final Test.

Rejected: There was a positive correlation significant at the .001 level. This positive correlation was interpreted to indicate that the degree to which concepts were learned in a part determined the amount retained at the end of the school year.

Hypotheses concerning students

1. There is no significant correlation between intelligence quotients of the sample and Unit I or II Test Scores.

Rejected: Positive correlations at the .05 and .001 levels respectively were found. Although these positive correlations existed, intelligence did not come out among the top three as accounting for variance on Unit I or II Test Scores when multiple regression analysis was used.

2. There is no significant correlation between intelligence quotients of the sample and the time in weeks spent on Units I or II.

Supported: No significant correlations were found.

3. There is no significant correlation between intelligence quotients of the sample and the total number of materials Parts completed.

Rejected: A positive correlation significant at the .01 level were found. Intelligence was a factor in predicting rate of progress through the materials.

4. There is no significant correlation between intelligence quotients of the sample and the Equated Final Test Score.

Rejected: A positive correlation significant at the .01 level existed. However, multiple regression indicated intelligence was not as important a variable in determining the degree of mastery of concept learning with these materials as Quantitative Thinking.

5. There is no significant correlation between the four scores of the Iowa Tests of Educational Development used and Unit I or II Test Scores.

Rejected: Positive correlations ranged in significance levels from .05 to .001 with a median and mode of .01. The multiple regression of these ITED Test scores as independent variables with Unit I or II Test Scores as dependent variables yielded only Quantitative Thinking Test scores among the first three and it accounted for the most variance in each case with values of 33.19 and 41.56 percent respectively.

6. There is no significant correlation between the four scores of the Iowa Tests of Educational Development used and time spent in weeks on Unit I or II.

Supported: No significant correlation existed in five of the eight comparisons. Rejected: Negative significant correlations existed at the .05 level for time spent on Unit I and scores on the tests, Background in the Natural Sciences and Quantitative Thinking, and the Composite scores.

7. There is no significant correlation between the four scores of the Iowa Tests of Educational Development used and the total number of materials Parts completed.

Supported: No significant correlation existed in three of the four cases. Rejected: Quantitative Thinking correlated significantly in a positive way at the .05 level.

8. There is no significant correlation between the four scores of the Iowa Tests of Educational Development used and the Equated Final Test Score.

Rejected: In all four comparisons positive correlations from .05 to .001 existed, the latter being the level of significance for Quantitative Thinking.

9. There is no significant correlation between the eight individual types of the sample indicated by the Myers-Briggs Type Indicator and the Unit I or II Test Scores.

Supported: In all comparisons but one, there existed no significant correlation. Rejected: A positive significant correlation existed at the .05 level between the Unit I Test Scores and intuition.

10. There is no significant correlation between the eight individual types of the sample indicated by the Myers-Briggs Type Indicator and the time in weeks spent on Unit I or II.

Supported: No significant correlations existed.

11. There is no significant correlation between the eight individual types of the sample indicated by the Myers-Briggs Type Indicator and the total number of materials Parts completed.

Supported: In all comparisons but one, no significant correlations existed. Rejected: There is a negative correlation significant at the .05 level between total Parts of the materials completed and extraversion. Extraverts may have preferred to react more with individuals than materials.

12. There is no significant correlation between the eight individual types of the sample indicated by the Myers-Briggs Type Indicator and the Equated Final Test Score.

Supported: In seven of the eight comparisons, no significant correlation existed. Rejected: A negative correlation significant at the .05 level existed for perception.

Hypotheses concerning materials

1. There are no learning hierarchies in the materials found by analysis of conceptual behavior of students on test items.

Rejected: Learning hierarchies were found to exist in the materials.

2. There is no significant correlation between the Unit I or II Test Scores of the sample and the time in weeks spent on each of those Units.

Rejected: Unit I had a negative significant correlation at the .01 level. Supported: Unit II Test Scores were not significantly correlated. There appeared to be a tendency for students who worked more rapidly through Unit I to get better Unit I Test Scores. This may well have been due to quantitative thinking abilities developed before using the physics materials.

3. There is no significant correlation between the time in weeks spent by the sample on Unit I and that spent on Unit II.

Supported: No correlation significant at the .05 level existed. The rate at which students completed these units does not appear to be consistent.

4. There is no significant correlation between the time in weeks spent by the sample on Units I or II and the total number of materials Parts completed.

Rejected: In both comparisons negative significant correlations at the .001 level existed. In general, it could be stated that students who completed units more rapidly tended to do so with some consistency so as to complete more total Parts of the materials.

Summary

Students who began the materials with quantitative thinking abilities progressed through Unit I of the materials more rapidly and learned more physics concepts in later units. Those students who began the materials without quantitative thinking skills appeared to develop some of these skills which were needed in later units. The amount of variance accounted for by Quantitative Thinking, which came out first during multiple regression analysis, was 33.19 percent on Unit I Test Score, 41.56 percent on Unit II Test Score, and 44.22 percent on the Equated Final Test Score. This positive progression of variance accounted for by Quantitative Thinking indicated that the materials became progressively more loaded for this ability.

Intelligence did not appear to be as important a variable in determining performance as was quantitative thinking ability. The rate at which a student progressed through units did not correlate significantly with intelligence. However, total Parts completed was significantly correlated. Rate of progress through materials was not consistent.

Of the four scores used from the Iowa Tests of Educational Development, the Quantitative Thinking Test score consistently correlated significantly with rate of progress through materials and Unit I and II Test Scores and the Equated Final Test Score.

The individual types as determined by the use of the Myers-Briggs Type Indicator did not generally correlate with rate of progress through materials or test achievement. The exceptions were a positive significant correlation between intuition and the Unit I Test Score, a negative significant correlation between extraversion and total Parts completed, and a negative significant correlation between perception and the Equated Final Test Score. All were at the .05 level of significance.

The performance in one unit as compared to other units, as determined by analysis of the Final Test, appeared quite consistent. This was attributed to two factors. First, learning hierarchies existed in the materials. Second, there was considerable quantitative loading in the materials. Concept hierarchies were established for translational and rotational motion, velocity and falling bodies, force, acceleration, and oscillation.

The interaction of students and materials indicated that rate of progress was not consistent from Unit I to Unit II but total rate was related to rate of progress through separate units. There was a tendency for those who worked more rapidly initially to get better test scores.

CHAPTER V

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

Restatement of Problem

The focus of this study was to assess the use of an individualized laboratory oriented high school physics program. This program was being used in a Black Hawk County School in the State of Iowa during the 1969-70 school year. These materials were individualized in that the students self-paced themselves through laboratory activities. In a sense the materials were programmed since there was a specific sequence of laboratory investigations that were explored. Some additional optional laboratory inquiries were provided for those desiring to work at a "higher level."

investigated in this study were an analysis of concept and processes of science found in the materials; characteristics of the sample; performance characteristics; learning hierarchy; and analysis of factors related to short and long-term learning, student characteristics related to learning, materials characteristics related to learning.

Major Findings

Concepts and processes

The first eight Parts, Parts 2-9, of the materials introduced the student to the program and to the models with which he worked. The broad concept areas included were mechanics in Parts 10 through 30 and wave motion in 28 through 35. Part 37 introduced electricity and magnetism which was the first Part of a third broad area being developed. Content was found traditionally organized. (For a more detailed scope and sequence of concepts included in materials, see Appendix A.)

The processes of science were found an integral part of the materials. Simpler processes were developed early in the materials and more integrative processes later. These were organized around data table models, graph models, sentence models, diagram models, descriptive models, and inquiry. Inquiry was utilized when no model was suggested. Processes were listed under models because the writer of the materials had stressed the use of these "symbolic organizers." (For a more detailed listing of processes of science, see Appendix B.)

Characteristics of the sample

The intelligence quotients of the sample ranged from 85 to 140. The mean was 116 and the median 117. The senior class at the school had a mean intelligence quotient of 112. All of the sample were seniors. Since 38 percent were at or below the class mean, it was concluded that intelligence was not a significant selection factor in determining who enrolled in this physics program.

Type data was obtained by the administration of the Myers-Briggs Type Indicator during the first week of school in the fall. The sample showed little difference in preference for behavior between extraversion and introversion or thinking and feeling. Intuition was preferred over sensing, 75 percent to 25 percent, and perception was preferred over judgment, 79 percent to 21 percent. Myers (1962) felt that scholastic potential appeared to be associated with introversion and intuition and hypothesized that introvert-intuition types have a greater "natural interest in scholastic activity and ES (extrovert-sensing) types have the least" (Myers 1962:44). Of introvert and intuition types only intuition seemed to be a dominant individual type and 35 percent had the introvert-intuition type. This combination was exceeded by the extravert-intuition type which comprised 40 percent of the sample. Self-paced laboratory oriented physics was possibly more appealing to the extravert-intuition type than would normally have been expected in what the investigator considered a very scholastic activity. This was possibly due to the environment for much student-student and student-teacher interaction. Introversion was not found to be significantly related to Test Scores. This would tend to support the findings of Szabo and Feldhusen (1970) who found that students with restraint (tendency toward introversion) achieved better in a traditionally-organized course as compared to an audio-tutorial group of college biology students when top thirds on the basis of achievement were compared. Extrovert-sensing types comprised only 12 percent of the sample. Individual types showed no consistency in correlating significantly with program test scores or rate of progress.

The sample was composed of 7 girls and 41 boys. The slightly less than 15 percent girl population was less than the national average of 26.4 percent for 1964-65 (Simon and Grant 1968:34). It did not appear that this physics program would increase the percentage of students enrolling in physics by appealing more strongly to high school girls.

The Iowa Tests of Educational Development (Lindquist 1960) standard scores showed that the sample percentile ranks ranged, based on Iowa norms, from a low of 1 to 10 to a high of 98 or 99 in the three tests Background in the Natural Sciences (mean=67), and Reading in the Natural Sciences (mean=75), and on Quantitative Thinking (mean=78); and the Composite (mean=80). Although the sample was not much above average in intelligence from their senior class, it appeared that as a group they were scholastically inclined.

Predicting success with materials

Unit I Test and Unit II Test Scores and the Equated Final Test Score were best predicted by ITED Quantitative Thinking standard scores with variances of 33.19, 41.56, and 44.02 percent respectively computed by multiple regression. Success on the materials related heavily to quantitative thinking abilities. The program was judged to contain substantial emphasis on mathematical models--sentence models, graph models, and data table models.

The Equated PSSC Score was best predicted by the Reading in the Natural Sciences Test (ITED) when the same independent variables used with other test scores were used.

When items from Part Tests that appeared on the Final Test (Parts Score) and the Final Test Score were used as dependent variables, the number of materials Parts completed was the best predictor with variances accounted for by multiple regression of 82.71 and 52.26 percent respectively. The student who completed more Parts answered more Part Test items that appeared on the Final Test and took more items on the Final Test because he was instructed to answer as many items as he had completed Parts. Thus these relationships were not surprising. (For multiple regression data, see Tables 6-11 on pp. 56-61.)

Learning hierarchies

Analysis of concepts in test items, test item type (Bloom 1956), test item correlations, analysis of item relationships and average cluster item difficulty were used to determine if learning hierarchies existed. Learning hierarchies were found for translational and rotational motion, velocity and falling bodies, force, acceleration, and oscillation. (For determined hierarchies, see Tables 15-19, pp. 74-78.)

These hierarchies were based on the theory of Gagne and Paradise (1961) that there are processes that must be mastered before an individual can exhibit a terminal behavior. They tested their theory and found the following: (Gagne and Paradise 1969:15) ". . .(b) a decreasing pattern of correlations can be shown between relevant basic learning ability factors and rate of learning for learning sets as one progresses upwards in the hierarchy;." If Iowa Tests of Educational Development scores are interpreted as "basic learning ability factors," rate of progress in completing Unit I was positively correlated with the tests, Background in the Natural

Sciences and Quantitative Thinking, and the Composite at the .05 level of significance. A significant correlation did not exist between them and rate on Unit II. Prior abilities appeared to become less significant.

Short and long-term learning

The Final Test Score and the Equated Final Test Score were correlated significantly in a positive direction with the Unit I and II Test Scores and the rate at which Unit I was completed. The performance on these tests, and rate at which the student completed Unit I, and total rate, as determined by total Parts completed, appear to be determined by quantitative thinking abilities. It was concluded that the materials were highly loaded for Quantitative Thinking. Multiple regressions with Unit I and II Test Scores and the Equated Final Test Score as dependent variables showed an increasing amount of variance accounted for by Quantitative Thinking-- 33.19, 41.56, and 44.02 percent respectively.

The Parts Score, those items that appeared in Part Tests and later on the Final Test, and the Final Test Score were positively correlated at the .001 level of significance with Quantitative Thinking. However, the difference between these scores, Final Test Score minus Parts Score, did not correlate significantly with Quantitative Thinking. Thus it was concluded that the amount that was learned was related to Quantitative Thinking but the amount of retention was not determined by quantitative thinking abilities. The difference in these scores on the same items was positively correlated with weeks spent on Units I and II at the .05 level. The conclusion drawn from this relationship was that those who progressed more slowly through Units I and II retained more of what they learned. This conclusion was supported by a negative correlation at the .01 level of significance between the diffefence in these scores and materials Parts completed and a negative .001 with the Parts Score.

Student characteristics related to learning

More able students achieved greater success with the materials. Intelligence quotients correlated significantly in a positive direction with the Unit I Test Scores at the .05 level, with the Unit II Test Scores at the .001 level, with the Final Test Score at the .001 level, and with the Equated Final Test Score at the .01 level. The more able students not only tended to get higher test scores but also tended to complete more Parts of the materials. Intelligence quotients correlated positively at the .01 level of significance with the total number of materials Parts completed during the school year.

The behavioral types as determined by use of the Myers-Briggs Type Indicator (1962) provided little significant data. Consistency in results were not found. Correlations significant at the .05 level were found to be positive between intuition and the Unit I Test Scores, negative between extraversion and total Parts completed, and negative between perception and the Equated Final Test Scores. The only tentative conclusion drawn was that extroverts possibly worked more slowly because they preferred interacting with other individuals more than laboratory activities. This deserves further study.

Materials characteristics related to learning

Learning hierarchies were found for translational and rotational motion, velocity and falling bodies, force, acceleration, and oscillation. The learning hierarchies were not found sequentially ordered from subordinate to terminal behavior. Many of the items in the hierarchies were of a quantitative nature. These data strongly indicate the need for program revision.

Rate of progress through the materials was not consistent, however, total Parts completed was significantly correlated to rate of completion of Units I or II at the .001 level. Unit I and II Test Scores were positively correlated at the .01 level of significance with rate of Unit I completion. Unit I dealt majorly with the mathematical models used in the program.

The enrollment of girls in physics was not substantial. This program does not appear to hold promise of increasing physics enrollments by appealing more strongly to girls.

Recommendations for Changes in the Materials

Recommendations for changes in the materials are based on the evidence collected for this study during the 1969-70 and 1970-71 school year at Columbus High School of Waterloo, Iowa and the investigator's analysis of the printed materials. Recommendations for changes are given below.

1. Learning hierarchies found in the materials by use of an analysis of test items exhibit little sequential progression from simpler tasks to more complex tasks. The writer of the materials should

examine the learning hierarchies carefully to aid in the sequencing of activities to progress from subordinate or precursor behaviors to the terminal behavior. Mini-tests might well be constructed and used to aid the student and teacher in determining when the student has acquired a certain behavior and is ready to proceed to the next task.

2. The evidence indicated that students who entered with quantitative thinking abilities progressed more rapidly through the materials and answered more test items correctly. Parts 2 through 9 contain the mathematics considered by the writer of the materials as necessary for success in later Parts. Evidence does not indicate Parts 2 through 9 to be adequately serving the intended function. It is recommended that a diagnostic quantitative thinking instrument be used to determine students who might skip Parts 2 through 9, students who have only minimal specific deficiencies, and those who need comprehensive instruction. Parts 2 through 9 might still be used but a better alternative might be to construct a branched program to be used by those that the diagnostic instrument indicates would profit from learning the necessary quantitative thinking abilities considered necessary for success with the materials.

3. An examination of the written materials evidenced the fact that the writer of the materials had not used internationally agreed upon symbols, units, and nomenclature consistently. This should be rectified so as to allow the student to read other physics

materials without the necessity, in some cases, of having to relearn symbols, units, and nomenclature.

4. An examination of the written materials and typing of test items resulted in the conclusion that there are too few activities requiring the highest types of behavior--synthesis and evaluation. The development of activities which teach higher level cognitive abilities should receive utmost attention. The writer of the materials should also construct instruments which assess the higher levels of the Cognitive Domain as well as those for the lower levels.
5. Use of the materials beyond experimental usage is not recommended at this time. The recommended changes should be made and the effect of these changes assessed before more wide spread usage is warranted and commercial publication of the materials is considered.

Recommendations for Further Research

Some additional problems warranting investigation that resulted from this study are listed below.

1. Girls were not found to enroll in the program, or in physics courses in general, in substantial numbers. Enrollment of girls in this program was approximately one-half of the national average. It might be that girls have an aversion to self-paced instruction and especially to this type of instruction that is laboratory oriented. A study of the enrollment of girls in self-paced laboratory instruction as compared to other types of instruction including several curricular areas appears warranted.

2. There was evidence in this study that those students who progressed more slowly retained proportionately more of what had been learned. The cause of this is unknown. Possible causes are the amount of time spent on the activities and the style of learning utilized. These two hypothesized causes might be found to be interrelated.
3. Further study should be made of the students who have used these self-paced laboratory oriented physics materials and who have gone on to take a college physics course to determine whether these materials were as successful in preparing them for further work in physics as other materials might have been. It is known that changes in these materials are needed. However, a follow-up study would provide needed evidence regarding how well these materials prepare the student for further study in physics.
4. The effectiveness of Parts 2 through 9 in developing quantitative thinking abilities necessary for success with later activities is not considered adequate. A comparative study involving a branched program and other alternatives would be most useful in determining the best method of teaching the necessary quantitative thinking abilities.
5. Reference is made by Richard (1969) that the self-directed learners are more prone to favor individualized instruction than are the non-self-directed learners. This may result in a selection factor when alternative modes of instruction are available or in not selecting to enroll in a program at all when alternatives are not available. Information of this type is needed for curriculum planning.

6. Extraversion was found in this study significantly correlated in a positive direction to slower progress through the materials. This can not be generalized to other self-paced programs at this time. Further information is needed concerning self-paced programs in several curricular areas to determine if this is generally the case.

APPENDIX A

CONCEPTS: SCOPE AND SEQUENCE

Page

Concept Chart 104

Table of Contents of Materials 110

CONCEPT	PART																																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
ACOUSTICS																																					
Acoustic Impedance																														●							
Sound																											●	●	●							●	
Sound Generators																												●									
Sound Pitch																													●								
Sound Transmission																												●	●								
Tuning Forks																			●	●								●									
ELECTRICITY & MAGNETISM																																					
Electric Discharges																																					●
Electrostatic Fields																																					●
Electrostatics																																					●
Impedance Matching																																		●			
Static Electricity																																					●

CONCEPT	PART																																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
FLUID MECHANICS																																					
Buoyancy																								●													
Fluid Mechanics																								●													
Water Waves																												●	●	●							
OPTICS																																					
Brightness																																	●		●		
Colors																																		●	●		
Diffraction																																		●			
Diffraction Gratings																																		●			
Illumination																																	●		●		
Lenses																																●	●				
Light																														●	●	●	●	●	●	●	
Light Transmission																															●	●	●	●	●		

CONCEPT	PART																																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
Mirrors																														●		●			●		
Monochromatic Light																																		●			
Optical Images																														●		●					
Optical Properties																														●		●			●		
Optics																														●	●	●					
Photometers																																	●				
Polarizing Filters																																			●		
Prisms																															●						
Reflectors																															●		●	●	●		
Refractive Index																															●	●			●		
Spectra																															●			●			
Spectrophotometers																																		●			

CONCEPT	PART																																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
PARTICLE PHYSICS																																					
Gamma Rays																																	●				
SOLID MECHANICS																																					
Falling Bodies												●		●	●	●	●						●	●													
Torsion																													●								
Vibration																											●	●	●	●							
THERMODYNAMICS																																					
Calorimetry																									●												
Convection (Heat Transfer)																									●												
Heat																							●	●	●	●		●									
Heat of Fusion																									●												
Heat of Vaporization																									●												
Specific Heat																									●												

CONCEPT	PART																																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
Temperature																									●												
WAVE PROPAGATION																																					
Angle of Arrival																														●	●				●		
Doppler Effect																																				●	
Electromagnetic Waves																																			●		
Microwaves																												●						●			
Propagation																												●	●	●							
Wave Transmission																												●	●	●	●				●		
MISCELLANEOUS MECHANICS																																					
Acceleration										●		●	●	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●							
Damping																											●										
Deceleration												●																									
Dynamics										●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●							

CONCEPT	PART																																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
Force (Mechanics)										●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●							
Inertia																						●							●	●							
Mechanics										●	●											●															
Moment of Inertia																													●	●							
Moments										●	●																		●	●							
Momentum																					●																
Motion				●	●					●	●	●	●	●	●	●	●	●	●	●	●	●	●	●						●							
Oscillation																		●	●	●			●				●	●		●							
Rotation					●	●							●				●	●	●										●	●							
Statics										●	●					●						●															
Torque										●	●																		●	●							
Velocity					●	●		●				●	●	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●						

TABLE OF CONTENTS

COPYRIGHT [illegible]
WALTER J. [illegible]
UNIVERSITY OF [illegible]

PART 1 INTRODUCTION TO THE COURSE

A message to the student regarding the nature of the course and general instructions for participation in the activities.

PART 2 AN INTRODUCTION TO MODELS AND OPERATIONS

Models and operations as guides to thinking.

Models and operations as valuable packages in which to organize and store knowledge

Models and operations as a means of communication

The road map as a model

Models and reality

Operations with the road map model

Communicating directions with a descriptive model

Communicating directions with a diagram model

Communicating directions with a sentence model

The blue print of a house as a model

Sketch of the house - a diagram model

Scale model of house - a structual model

Models and phases of reality

A data model of distance and time

Extrapolation and interpolation of graph models.

PART 3 GRAPH MODELS

Advantages of graph models

The story of the race between the tortoise and the hare told as a descriptive model and as a graph model

Speed represented as the slope of a graph line

A student-constructed graph model

The meaning of a negative slope of a graph line

Using positive and negative time and space representations

(Part 3 - continued)

The use of general graph models

Constructing and using specific graph models

A check of understanding of graph models

PART 4 SENTENCE AND DIAGRAM MODELS

The importance of an adequate background in mathematics

A diagram and corresponding sentence model for the area of a trapezoid

Symbols used as a code of representations in sentence models

The code of instructions in sentence models

Transforming sentence models

Developing and using sentence models

The application of geometry in processing diagram models

Laboratory: Translation motion

Practice exercises with diagram and sentence models

PART 5 KINDS OF MOTION

Examples of translational and rotational motion

Radian measure of rotation

Laboratory: Rotational motion

PART 6 FRAMES OF REFERENCE

Laboratory: Problems simplified by a change of frame of reference

Models of reality determined by the choice of reference frames

Laboratory: Check of ability to apply frames of reference to unique situations

PART 7 DIMENSIONS AND DIMENSIONAL OPERATIONS

One-dimension systems

Two-dimensional systems

Three-dimensional systems

BEST COPY AVAILABLE

(Part 7 - continued)

Four-dimensional systems

Operations with numbers and dimensions

The selection of dimensions

The use of dimensional codes

Supplementary exercises with dimensional operations.

PART 8 VECTOR QUANTITIES

Scalor quantities described as two-part quantities

Vector quantities described as three-part quantities

Distance considered as a scalor quantity

Distance considered as a vector quantity

Vector considerations in a football play

Vector components in a football play

The choice of vector components

Some applications of vector components

PART 9 VARIATION

Variables and constants

Introduction of the constant of variation

Laboratory: Experiences related to a constant of variation for direct variation

Direct and inverse variation

Laboratory: Experiments related to inverse variation

The graph model of direct variation (first power of variables)

The graph model of inverse variation first power of variables

Using reciprocals to obtain a straight line graph for inverse variation

Using logarithm functions to obtain a straight line graph for inverse variation

Introduction to multiple variation

Dimensional operations with multiple variation

(Part 9 - continued)

Laboratory: Experiences involving multiple variation

Supplementary exercises to check the understanding of the use of variation in physical problems.

PART 10 ZERO ACCELERATION

A review of distance-time graph models

Introduction to positive, negative, and zero acceleration as changes in speed

Laboratory: Activities with balanced forces and zero acceleration

Using the principle of zero acceleration to measure the force of friction

Laboratory. Introduction to balanced torques or moments of force that produce zero acceleration

Laboratory: Use of balanced torques to introduce idea of center of gravity

PART 11 MACHINES

Simulation of the ideal, frictionless machine

The wheel and axle as a torque machine

The ideal mechanical advantage of a machine

Introduction of the force of friction

The actual mechanical advantage of a machine

Predicting the ideal mechanical advantage of a four-rope pulley

Laboratory: Measuring the ideal mechanical advantage of the four-rope pulley by the zero acceleration method and the relative distance method.

Laboratory: Predicting and measuring the ideal and actual mechanical advantage of a single movable pulley

Predicting the ideal mechanical advantage of the inclined plane

Laboratory: Measuring the ideal and actual mechanical advantage of the inclined plane

Predicting the ideal mechanical advantage of a compound machine

Laboratory: Measuring the ideal and the actual mechanical advantage of a compound machine

PART 12 MEASURING CONSTANT TRANSLATIONAL ACCELERATION

Developing some elementary models of constant acceleration from a thought experiment for a ball rolling down an incline

Developing an acceleration graph model of the ball rolling down an incline

Representing space covered as the area under the graph line of an acceleration graph

Formulating a sentence model for space covered, by finding the area of the graph which represents space, for objects starting from rest

Developing a set of sentence models for constant acceleration of objects starting from rest

Using a graph model of the motion of objects with an initial velocity and constant acceleration to develop corresponding sentence models

Laboratory: A check of the models for an initial velocity and constant positive acceleration

Developing models for an initial velocity and constant negative acceleration

Laboratory: A check of the models for an initial velocity and constant negative acceleration

Laboratory: A check of the use of the knowledge of constant acceleration

PART 13 MEASURING CONSTANT ROTATIONAL ACCELERATION

Developing models for constant rotational acceleration by the use of analogy with the corresponding models for constant translational acceleration

Laboratory: Devising checks of the models developed

PART 14 THE ACCELERATION OF GRAVITY AT THE SURFACE OF THE EARTH

The problem posed by the rate at which objects fall

Procedures that can be used to overcome this problem of the rate of fall

Laboratory: The measurement of the acceleration of gravity by various procedures

A Hand Book check of the acceleration of gravity at different locations on the surface of the earth

PART 15 TRAJECTORIES

The trajectory of an object projected horizontally

(Part 15 - continued)

Vector analysis of motion of a projected rock

A set of sentence models for the motion of an object projected horizontally

Laboratory: Verification of models for an object projected horizontally

Exercises to check understanding of motion of an object projected horizontally

Transition from a parabolic to an eliptical flight path as the direction of the gravity force vector changes

A theoretical analysis of the trajectory of a punted football

PART 16 FORCE MASS AND ACCELERATION

Force requirements for zero acceleration

Fluid friction and terminal velocity

Galileo's discovery of the relationship between the mass of an object and its acceleration in free fall

The variation that fits the discoveries of Galileo

Laboratory: A check of the variation for a constant accelerating mass

Laboratory: A check of the variation for a constant accelerating force

Arriving at the absolute dimensions of force - eliminating the constant of variation

Development of the dimension, the slug, for absolute dimensions of mass

Exercises to check the understanding of absolute dimensions of force

Relating gravitational dimensions of force with absolute dimensions of force

The conversion of gravitational dimensions to absolute dimensions of force

The concept of g's of force

PART 17 CENTRIPETAL ACCELERATION

Velocity - a vector quantity

Acceleration - a measure of the change in the magnitude part of the velocity vector

Acceleration - a measure of the change in the direction part of the velocity vector

A diagram model of centripetal acceleration

(Part 17 - continued)

Developing a sentence model for centripetal acceleration using the arc procedure

Developing a sentence model for centripetal force

Laboratory: Verification of the sentence model for centripetal force

Exercises to check the understanding of centripetal acceleration and force

Application of centripetal force and gravitational force vectors to the banking of highways and airplane wings

PART 18 CHANGING ACCELERATION AND SIMPLE HARMONIC MOTION

A review of graph models for accelerated motion

The acceleration of a swinging pendulum bob

Forces acting on the swinging pendulum bob

A descriptive and sentence model of simple harmonic motion

Producing exact s.h.m. by using the shadow of a rotating peg

Theoretical verification that the acceleration of the shadow of the revolving peg is directly proportional to the displacement from the equilibrium point

Laboratory: Shadow graphing of the vector acceleration of the shadow of the revolving peg

Laboratory: Shadow graphing the velocity vector of the shadow of the revolving peg

Indicating the direction of motion and the position of the shadow of the revolving peg by designating its phase

The period and frequence of simple harmonic motion

Laboratory: Phase relationships between two s.h.m.'s with the same period demonstrated by shadow graphs

Laboratory: Phase relationship and beats when two s.h.m.'s have different periods demonstrated by shadow graphs

PART 19 S.H.M. VELOCITY ACCELERATION POSITION

A vector approach to the velocity of simple harmonic motion

Laboratory: A check of the velocity models developed for simple harmonic motion

Models for the acceleration of simple harmonic motion

(Part 19 - continued)

Laboratory: A check of the acceleration models

Laboratory: Plotting a position graph of s.h.m. using the shadow graph method

Laboratory: Plotting the position graph of s.h.m. using a swinging pendulum

Laboratory: Plotting phase differences on a graph of position

Laboratory: Graphing the motion of the prong of a tuning fork by making a trace on smoked glass

Laboratory: Graphing the motion of the prong of a tuning fork using an oscilloscope

PART 20 THE FREQUENCY OF S.H.M.

Developing a model for the period of simple harmonic motion

Developing a model for the period of a mass oscillating on a spring

Laboratory: A check of the model developed for the period of a mass oscillating on a spring

Developing the model for the period of a pendulum

Combining two s.h.m's at the right angles to produce Lissajous Figures

Reading out frequency and phase differences using Lissajous Figures

Laboratory: Comparing the frequency of two pendulums using Lissajous Figures

Laboratory: Comparing the frequencies of two tuning forks using Lissajous Figures

PART 21 IMPULSE AND MOMENTUM

Models relating impulse and momentum

Laboratory: An experience with internal forces and momentum

Supplementary exercises to check the understanding of impulse and momentum

PART 22 ENERGY AND MACHINES

Comprehension of the equivalence of mass and energy

Attempts to define mass

Attempts to define energy

Energy and mass an experience concept

(Part 22 - continued)

Laboratory: Some preliminary experiences with energy of position and energy of motion

Zero acceleration for a frictionless machine

Center of gravity and energy of position

Center of gravity, energy of position, and moments of force using "frictionless" pulley system

Energy approach to zero acceleration for a machine with friction

Equating loss of mechanical energy to a gain in heat energy

Exercises to check the understanding of the principles of energy

Efficiency of machines as related to energy changes

Dimensions of energy

PART 23 ENERGY OF MOTION

The equivalence of loss of energy of position and gain in energy of motion

Transition from energy of position equivalence to the mass-speed equivalence for energy of motion

Laboratory: An experience in equating loss of energy of position with a gain in energy of motion

The equivalence of loss of energy of position and gain in energy of motion for the inclined plane

The equivalence of loss of energy of position and gain in energy of motion for a pendulum bob

Laboratory: Experiences to check the equivalence of loss of energy of position and gain in energy of motion for the pendulum bob

Using energy models as a convenient solution to trajectory problems

PART 24 ENERGY-TERMINAL VELOCITY AND BOUYANCY

Terminal velocity explained by equating loss of energy of position and gain in heat energy

Terminal velocity in air as related to size mass and shape of object

Terminal velocity for flowing water

The experimental approach to Archimedes' principle

(Part 24 - continued)

The pressure approach to Archimedes' principle

The energy approach to Archimedes' principle

Laboratory: Experiences with Archimedes' principle

Exercises to check the understanding of the energy approach to bouyancy

PART 25 HEAT ENERGY

Historical development of the fluid hypotheses of heat

Transition to energy hypotheses of heat

Discovery of the equivalence of mechanical energy and heat energy

The measurement of the amount of heat energy

The calorimeter method for measuring the exchange of heat energy

Laboratory: Experiences to determine the water equivalent of a calorimeter

Laboratory: Determination of the relationship between the Joule of mechanical energy and the calorie of heat energy

The specific heat of materials

Laboratory: Measurement of the specific heat of a metal

Laboratory: Measurement of the temperature of a red-hot nail

Laboratory: Measurement of the heat of fusion of ice

Laboratory: Measurement of the heat of vaporization of steam

PART 26 POWER

Power as the rate of energy transfer

The dimensions of power - the watt

The establishment of the horse power

Laboratory: Experiences in measuring the watt and horse power output of muscles

Laboratory: Experience in measuring the efficiency of a small electric motor

The conversion of ergs of energy to Joules of energy

Exercises to check the understanding of the principles of power

PART 27 ENERGY-FORCED VIBRATIONS AND RESONANCE

Free vibrations and forced vibrations

Loss of energy by freely vibrating bodies

Supplying energy to vibrating bodies

Laboratory: Experiences with forced vibrations, energy transfer, and mechanical resonance - combining forced and free vibrations

Laboratory: Experiences with the electrical analog of mechanical resonance

Laboratory: Experiences with the natural frequency - force vibration and resonance of vibrating strings

Laboratory: Experiences with the factors that determine the resonant frequency of vibrating strings

Laboratory: Harmonic frequencies for vibrating strings

PART 28 WAVES, ENERGY IN MOTION

Common experiences related to energy being transferred by waves

Energy transfer by Bell Wave machine

Theoretical development of wave amplitude and wave energy transfer

Laboratory: Verification of theoretical developments using a stretched spring

Measuring the velocity of energy transfer - velocity of the waves

Laboratory: Measurement of the velocity of waves on the Bell Wave machines by direct measurement and by using standing waves

Laboratory: Measurement of the velocity of sound waves in a closed tube

Laboratory: Direct measurement of sound wave velocity in open space

Laboratory: The measurement of the speed of sound waves in metal

Laboratory: Using standing waves to measure the frequency of a sound source

Laboratory: Using standing waves to measure the frequency of a micro wave projector

PART 29 THE FACTORS THAT DETERMINE WAVE VELOCITY

A theoretical approach to the velocity of waves on the Bell Wave machine

Laboratory: Verification of the theoretical development of the velocity of waves on the Bell Wave machine

(Part 29 - continued)

Laboratory: The relationship between wave velocity and the amount that a spring is stretched

Laboratory: Factors that determine the velocity of waves on the magnet board

Kinds of waves: Transverse, longitudinal, torsional, and eliptical

The nature of water waves

A Lissajous concept of water waves

Locating an earth quake by measuring the reception of transverse and longitudinal waves

An image model of sound waves

The factors that determine the velocity of sound waves

PART 30 REFLECTION OF WAVE ENERGY

Reflection of waves on the Ball Wave machine

Reflection of wave energy on a spring

Reflection of wave energy on the magnet board

The concept of wave impedance

Developing models for wave impedance

Reflection of waves at a boundary of zero impedance

Reflection of waves at an infinite impedance boundary

Reflection at a boundary for which the impedance increases

Reflection of waves at a boundary for which the impedance decreases

Reflection of water waves at different impedance boundaries

Reflection of eliptical water waves

Reflection of light waves at the surface of a plane mirror

The wave front - ray model of light waves

Images produced by the reflection of light waves from a plane mirror

PART 31 REFRACTION OF LIGHT WAVES

A wave front model of refraction with a change in velocity

(Part 31 - continued)

Developing a model to relate the index of refraction and velocity in the two media

Laboratory: Check of the theoretical developments for the index of refraction

Index of refraction and apparent elevation

Wave front and ray models for apparent elevation

Sentence models for apparent elevation

Laboratory: Using a microscope to measure apparent elevation

Index of refraction and the critical angle

Laboratory: Using the optical disk to measure the critical angle and index of refraction

Use of critical angle in reflecting devices for optical instruments

Refraction of light by 60° prism. The spectrum of light

The relationship between wave length and velocity for light waves in glass

PART 32 LENSE AND MIRROR IMAGES

A ray model of an ideal convex lense being used as a burning glass

Laboratory: Discovering spherical aberration using a convex lense and an optical disk

Laboratory: Discovering the effect of spherical aberration on an image of the sun

Chromatic aberration and achromatic lenses

A wave front model of an ideal convex lense

A ray model of a diverging lense

A wave front model of a diverging lense

Using a converging lense to project an image on a screen

Diagram model of image formation on a screen

A mathematical processing of the diagram model of image projection

Laboratory: An application of the lense model developed by processing the diagram model

A lense used as a magnifying glass

(Part 32 - continued)

Laboratory: A convex air lense in glass

Exercises to check understanding of defraction by a lense

Images produced by concaved and convex mirror surfaces

Laboratory: Comparing image model of converging mirror with model of a converging lense

PART 33 TRANSMISSION OF WAVE ENERGY

The importance of regulating the amount of energy transmitted

Loss of wave energy in being converted to other forms of energy

Factors that determine the amount of absorption of wave energy by the medium

Laboratory: Measuring the absorption of gamma rays

Laboratory: Measuring the reflection of gamma ray energy

Laboratory: Measuring the absorption of infra red wave energy

Laboratory: Measuring the absorption of micro wave energy

Impedance matching and transmission of wave enrgy

Spreading of wave energy

Beaming wave energy

Calculating the loss of wave energy through spreading

Laboratory: Checking the theoretical models for loss of wave energy by spreading

Candle power and foot candles as measures of light energy transmitted and received

Laboratory: Comparing illumination with a photometer

PART 34 WAVE INTERFERENCE

Recall of production of standing waves

Laboratory: Combining waves on the Bell Wave machine

Laboratory: Combining in phase and out of phase sound waves

Producing coherent waves

(Part 34 - continued)

Laboratory: Interference and reinforcement of micro waves

Laboratory: Determining the phase change when micro waves are reflected from a Lloyd's mirror

Laboratory: Interference and reinforcement of micro waves from two slits

Huygen's wavelet model

Wavelet model applied to a diffraction grating

Laboratory: Using a diffraction grating to produce a spectrum on a screen

Laboratory: Checking the sentence model for the diffraction grating

Laboratory: Using a spectroscope to measure the wave length of light

Producing colors by interference

Laboratory: Interference of incident and reflected micro waves

Laboratory: Interference of reflected light waves

PART 35 POLARIZATION OF TRANSVERSE WAVES

Laboratory: Polarization of micro waves

Laboratory: The effect of polaroid lenses of light waves

Atomic model of unpolarized light waves

Amount of light transmission in relationship to the axis of the polarizer and analyzer

Laboratory: Double refraction of calcite crystal

Laboratory: Polarization by reflection

Theoretical explanation of Brewster's angle

Laboratory: Predicting and measuring Brewster's angle for glass

Brewster's law and the nature of light waves

Polarization by scattering of light

Laboratory: The sunset experiment

Laboratory: The mechanical analog of polarization

PART 36 DOPPLER'S PRINCIPLE

Recall of observation of Doppler's Principle for sound waves

(Part 36 - continued)

Using string belts to simulate Doppler's Principle

Laboratory: Source of waves and receiver of waves stationary with respect to the wave medium

Laboratory: Observer stationary - the source in motion with respect to the wave medium travel. The source is moving toward the observer

Laboratory: The observer stationary - the source in motion with respect to the wave medium. The source moving away from the observer

Laboratory: Source stationary - the observer in motion with respect to the wave medium
a. Observer moving toward the source
b. Observer moving away from the source

Laboratory: Observer and source both in motion with respect to the wave medium
a. Observer and source moving toward each other
b. Observer and source moving away from each other

Laboratory: Doppler effect when waves are reflected from a surface that is in motion with respect to the wave medium

Applications of Doppler's Principle

PART 37

Review of ideas related to energy

Forces of repulsion and attraction in electrostatic force fields

Laboratory: Checking Coulomb's law for electrostatic forces

Exercises to check understanding of Coulomb's law

The statcoulomb and the Coulomb of electrical charge

Relating electrical energy and electrical power

Laboratory: Using a kilowatt hour meter to measure Wattage

APPENDIX B

PROCESSES: DESCRIPTION AND LISTING

Page

Descriptions of the Processes of Science 127

Listing of Processes

Observing 129
Recording Data 138
Measuring 144
Using Space/Time Relationships 155
Using Numbers 167
Communicating 176
Investigating 187
Inferring 195
Classifying 201
Interpreting Data 207
Predicting 215
Controlling Variables 223
Defining Operationally 230
Formulating Hypotheses 236
Formulating Models 243
Experimenting 250

DESCRIPTIONS OF THE PROCESSES OF SCIENCE

1. Observing: Distinguishing attributes of object or what happens in an event. A systematic perception of the environment.

2. Recording Data: Systematically collecting the perceptions of observations in an accurate, complete, and concise way by pictoral, numerical and written means.

3. Measuring: Assigning reasonable estimates to the dimensions of things in the physical world, progressing from relative terms toward the precise use of standard units.

4. Using Space/Time Relationships: Comparing the position, size, shape, motion, and direction of objects in space.

5. Using Numbers: Discovering and communicating the quantitative properties and relationships of objects.

6. Communicating: Passing and receiving information in an accurate, complete, and concise way whether by oral, pictoral, graphic, or written means.

7. Investigating: Systematically using the primary processes to arrive at an idea, concept, or generalization.

8. Inferring: Systematically integrating information from an observation with past experiences to arrive at a tentative idea. Inferring is at a higher level than guessing, but lower than predicting.

9. Classifying: Grouping a collection of objects or ideas into sets with common characteristics, thus enabling the learner to make meaningful and useful relationships in the process of developing a concept.

10. Interpreting Data: Developing and stating only those ideas or generalizations that can be supported by the observed and recorded information.

11. Predicting: Forecasting a specific outcome with reasonable certainty based upon an observed set of events or data.

12. Controlling Variables: Isolating and deliberately manipulating one or more factors in order to discover cause-effect relationships.

13. *Defining Operationally*: Making a statement which sets tentative limits of a description of a work, event, idea or process.

14. *Formulating Hypotheses*: Stating a line of reasoning tentatively adopted to explain observed facts or conditions, designed as a guide to further investigation which may lead to greater understanding of a concept, idea, or generalization.

15. Formulating Models: Representing an idea by physical, mathematical, pictoral, or written means in order to explain observations.

16. *Experimenting*: Integrating all of the other processes of science (skills of inquiry) by deliberately and sysematically formulating problems, thinking out procedures, controlling variables, making observations, and arriving at ideas, concepts, generalizations, or conceptual schemes.

OBSERVING

Data Table Model

2- 9- 1	Identifying data table model
2- 9- 1	Identifying number pairs
2- 9- 1	Identifying intervals
2- 9- 1	Identifying dimensions
2- 9- 1	Identifying relationship between numbers of number pair
2-11- 2	Identifying relationship between number pair and plotted point on a graph model
8-13- 6	Identifying vector magnitude
8-13- 6	Identifying vector direction
9- 4- 1	Identifying inverse variation
9- 4- 1	Identifying constant of variation
9- 4- 1	Identifying constant of variation dimensions
9- 4- 1	Identifying constant of variation number value

OBSERVING

Graph Model

2-11- 2	Identifying coordinate axis graph model
2-11- 2	Identifying number pairs
2-11- 2	Identifying point plot of number pair
2-11- 2	Identifying dimensions of axes
2-11- 2	Identifying line connecting plotted points of number pairs
2-11- 2	Identifying points in time
2-11- 2	Identifying points in space
2-12- 3	Identifying space intervals
2-12- 3	Identifying time intervals
3- 4- 1	Identifying relationship of slope of line to speed
3- 4- 1	Identifying terminal space (distance)
3- 4- 1	Identifying origin of time and space
3- 4- 1	Identifying relationship of constant slope to constant speed
3- 4- 1	Identifying relationship of zero slope to zero speed
3- 4- 1	Identifying relationship of $\Delta y/\Delta x$ to $\Delta D/\Delta t$
3-10- 5	Identifying relationship of negative slope to negative direction (velocity)
3-10- 5	Identifying relationship of positive slope to positive direction (velocity)
3-12- 7	Identifying analogous relationship of positive and negative quadrants of x and y to positive and negative time and distance plots
3-14- 9	Identifying relationship of changing slope of line to acceleration

3-23-16	Identifying speed of object
3-26-17	Identifying tangent line drawn at point on line with changing slope
7- 4- 1	Identifying one dimensional graph model
7- 5- 2	Identifying polar coordinates graph model
7- 6- 3	Identifying three dimensional graph model
8-13- 6	Identifying vector direction
8-13- 6	Identifying vector magnitude
8-13- 6	Identifying vector resultant
10- 1- 1	Identifying relationship of changing slope of line to deceleration

OBSERVING

Sentence Model

4- 2- 1	Identifying sentence model
4- 2- 1	Identifying representative symbols
4- 2- 1	Identifying instructions code
4- 3- 2	Identifying unknown
4- 6- 4	Identifying transformed sentence models
4-16-11	Identifying trigonometric functions
4-17-12	Identifying pythagorean theorem
7-11- 5	Identifying dimensions
7-11- 5	Identifying analogous relationship of processing dimensions and algebraic symbols
9- -	Identifying constant of variation
9- -	Identifying direct variation
9- -	Identifying inverse variation

OBSERVING

Diagram Model

4-12- 8	Identifying diagram model
4- -	Identifying two and three dimensional geometric shapes
4-12- 8	Identifying tangent to a circle
5- 7- 6	Identifying laboratory set up
6- -	Identifying frame of reference
7-17- 5a	Identifying dimensions
8- -	Identifying scalar quantities
8- 3- 1	Identifying vector quantities
8- 3- 1	Identifying vector quantity bar symbol ($\overline{M}$)
8- 3- 1	Identifying vector diagram
8- 8- 2	Identifying vector direction as represented by arrow
8- 8- 2	Identifying vector magnitude as represented by arrow length
9- 5- 2	Identifying inverse variation of rotational speed to pulley size
11-16- 6	Identifying inclined plane
11-17- 7	Identifying force vectors

OBSERVING

Descriptive Model

3- -   Identifying descriptive model

3- 9- 3 Identifying written descriptive model

3- 9- 3 Identifying symbolic symbols

OBSERVING

Inquiry

3-17-11	Identifying time interval
3-17-11	Identifying distance an object moves per time interval
3-17-12	Identifying distance per time rate of motion
5- 2- 1	Identifying translational motion
5- 2- 1	Identifying rotational motion
5- 3- 3	Identifying relationship of radius to radian
5- 3- 3	Identifying radians per circle
5- 3- 3	Identifying degrees per radian using degree scale protractor
5-10- 7	Identifying cyclic phenomena
6- 4- 2	Identifying frame of reference
10- 3- 4	Identifying static balance
10- 3- 4	Identifying dynamic balance (zero acceleration)
10- 3- 4	Identifying equal masses
10- 3- 4	Identifying force of friction
10- 9- 6	Identifying weight of object by weighing it
10-17-13	Identifying moments of force
11- 1- 1	Identifying effort force
11- 1- 1	Identifying resistance force
11- 9- 3	Identifying number of ropes in pulley system supporting resistance
16-11- 3	Identifying accelerating force
16-11- 3	Identifying volume of liquid in milliliters
18-17- 7	Identifying frequency of simple harmonic motion

18- -	Identifying changes in velocity of object in simple harmonic motion
22-24-13	Identifying an object with potential energy
23- 2- 1	Identifying an object with kinetic energy
24- 1- 1	Identifying weight of water displaced by an object by weighing it
24- 7- 2a	Identifying buoyant force
25-11- 1	Identifying temperature of water
27-11- 2	Identifying micro ammeter reading
27-22-10	Identifying node and anti-node of vibrating wire
28- 7- 1	Identifying phase of arm of Bell Wave Machine in degrees and radians
28-13- 5	Identifying standing waves on Bell Wave Machine
28-17- 6	Identifying resonant levels in a glass cylinder with adjustable water levels
28-19- 7	Identifying one wavelength produced by an audio-generator
30- 7- 1	Identifying reflection of waves
30- 9- 6	Identifying phase change of transmitted waves
30-13-14	Identifying a liquid with the same impedance as glass
30-22-19	Identifying angle of reflection
30-23-21	Identify image reflected at 90° angle to be reversed and upside down
31-16- 9	Identifying critical angle of glass
32- 3- 2	Identifying spherical aberration of a lens
32-16- 9	Identifying double concave air lens as diverging lens
32-17-12	Identifying image of hot air from a flame on a screen when light is shone through it
32-18-13	Identifying image enlargement of converging mirror

32-18-13	Identifying image shrinking of diverging mirror
33- 2- 1	Identifying effects of lead and polyethylene shields on gamma ray count using scalar with geiger tube with beta shield
33- 4- 3	Identifying effect of material thickness on gamma ray absorption

RECORDING DATA

Data Table Model

2-11- 2	Describing data number pairs from a coordinate axis graph model
3-17-11	Describing measured distance traveled during a given time period
9- 4- 1	Describing measured time needed to travel a given distance
9- 6- 4	Describing measured radius of pulleys
19-11- 6	Describing displacement and phase angle of an object in simple harmonic motion
27-11- 2	Describing micro ammeter readings for different radio frequency generator frequency settings
33-11- 7	Constructing a data table model of water depth and ohm meter reading for infrared waves
37-10- 1	Describing measured length of pendulum arm, separation of pendulum masses, and distance pendulum mass has moved from perpendicular for a static electricity investigation

RECORDING DATA

Graph Model

14- 8- 1	Collecting free fall time and distance data with spark tape apparatus
15- 7- 4	Describing x and y components of an object with an initial horizontal velocity by shadow graphing it
19-16- 7	Describing the motion of a pendulum by attaching a pen to it that marks on a paper belt moving at a constant rate perpendicular to its path of swing
19-16- 7	Describing the motion of a tuning fork by having it make a trace on smoked glass
28-12- 4	Collecting potential energy and kinetic energy time and distance data of a spring in simple harmonic motion with spark tape apparatus
33- 4- 3	Constructing a graph of thickness of the medium and gamma ray count rate on a coordinate axis graph
33-11- 7	Constructing a graph of water depth and ohm meter reading for infrared waves

RECORDING DATA

Sentence Model

RECORDING DATA

Diagram Model

27-22-10	Drawing a vibration diagram of the harmonics produced
34-11-13	Completing a diagram of linear waves passing through openings in paraffin blocks by drawing curved lines to represent waves
34-19-17	Labeling observed colors of spectra on a diagram model

RECORDING DATA

Descriptive Model

5- 3- 3	Describing number of radians in one revolution
5- 3- 3	Describing measured degrees in a radian
9- 7- 7	Describing the graph line of an inverse variation as a hyperbola
22-12- 5	Describing observations made of a weighted disc rolling on an inclined plane
30-12- 9	Describing data that indicates that the impedance of a brass strip is infinite to water waves
34- 1- 1 2	Describing in general the amplitude of combined pulses relative to the amplitude of individual pulses from each end when they meet in phase and out of phase
35- 9- 7	Describing observation of a dot on a piece of paper through a calcite crystal

RECORDING DATA

Inquiry

31-16- 9 Describing measured critical angle of a glass air boundary

MEASURING

Data Table Model

MEASURING

Graph Model

3- 4- 1	Distinguishing relative speed from slope of lines on graph model
3- 4- 1	Describing changes in time on a graph model
3- 4- 1	Describing points representing space/time events on graph model
3- 4- 1	Describing intervals of time on graph model
3- 4- 1	Describing intervals of distance on graph model
3- 7- 2	Constructing line representing average speed on graph model
3-10- 4	Describing a line with zero slope
3-14- 8	Describing a negative time plot
3-14- 9	Describing changing speed from changing slope of line on space/time graph model
3-17-12	Constructing graph model of measured changes in space and time
3-17-12	Applying rules for estimating distances per given time from space/time graph model
7- 4- 1	Describing space using one dimensional model
7- 5- 2	Describing space and time using polar coordinates
7- 6- 3	Describing space and time using two dimensional model
7-11- 5	Describing space and time using three dimensional model
9- 7- 6	Constructing graph of direct variation
9- 7- 7	Constructing graph of inverse variation
9- 8- 9	Constructing logarithm graph of inverse variation
12- 5- 4	Distinguishing area under line of speed/time graph to represent distance traveled
22-21- 8	Describing how the area of a graph representing the amount of heat energy was drawn

22-21- 9	Distinguishing portion of one plot to be equal in area to another plot
22-22-10	Describing machine efficiency from graphed data
27- 8- 1	Constructing a resonance curve for mechanical resonance

MEASURING

Sentence Model

15- 4- 3	Applying formula, $S = \frac{1}{2}at^2$, to determine time of freefall
15- 4- 3	Applying formula, $v = at$, to determine final velocity, for given time interval
15- 7- 4	Applying formula, $-y = Kx^2$, to find values of y when those for K and x^2 are given
15-14- 5	Determining projectile range when shot from different heights at similar velocities
15-15- 6	Determining initial velocity of projectile shot horizontally by knowing distance and height
15-16- 9	Determining distance of one degree on earth's surface if circumference is 25,000 miles
15-20-10	Applying formula, $S = \frac{v_o^2 \sin 2\theta}{2g}$, to determine angle for maximum height of projectile
21- 8- 5	Describing the relationship between two masses and their velocities when the same force acts on them
21-10-10	Determining velocity of bullet fired into block of wood by knowing block weight, bullet weight, and velocity of block and bullet when bullet stops in block
31-10- 6	Applying formula to determine apparent elevation of an object at a given depth at a given index of refraction

MEASURING

Diagram Model

3-11- 6	Describing positive and negative velocity determined by direction
4-12- 8	Constructing geometric proof that angles are equal
4-14- 9	Applying formulae for determining area of two and three dimensional objects
4-17-12	Applying pythagorean theorem to find length of sides of right triangles
6- 3- 1	Distinguishing a frame of reference
8- 3- 1	Constructing representations of distances with vectors
8- 3- 1	Constructing and solving vector problems using scale drawing
8- 8- 2	Describing vector magnitude using trigonometric functions
8-12- 6	Describing vector direction using trigonometric functions
9- 6- 3	Describing direct variation
9- 6- 3	Describing inverse variation
10-13-10	Distinguishing vector representations of forces
10-13-10	Distinguishing angle (Sin θ) at which force acts in moment of force
11- 9- 3	Applying rule for estimating ideal mechanical advantage (IMA) of a pulley system
12- 3- 1	Determining number pattern of distance per second of constant translational acceleration to determine new members
18-15- 6	Distinguishing phase angle of simple harmonic motion
18-17- 7	Describing phase and amplitude of simple harmonic motion
22-18- 7	Describing heat energy produced by a four string pulley system
22-24-13	Describing potential energy loss as it moves from maximum displacement to equilibrium point

23- 2- 1	Describing energy of falling object in gram centimeters and in ergs
30-16-16	Describing relationship of virtual point source to mirror with real point source in scale drawing

MEASURING

Descriptive Model

3- 9- 3	Constructing a coordinate axis graph from a descriptive model
9-14-12	Demonstrating variation approach to indirect measurement
12- 3- 1	Ordering a series of distance numbers for second time intervals for $a = 3 \frac{\text{cm}}{\text{sec}^2}$
16-23-15	Describing force in g's of force
17-17- 6	Distinguishing the angle that a road should make with horizontal for a given speed and curvature
26-13- 6	Describing minimum horsepower needed to raise a given weight a given distance in a given time
26-13- 6	Describing cost of operating a ½ horsepower motor for a given time at a given rate per kilowatt hour
26-13- 6	Describing velocity an ideal electric motor can raise a given weight if it "draws" a given number of amperes at a given voltage
26-13- 6	Describing conversion system for horsepower to watts
26-13- 6	Describing force on generator handle of a given length that is turned at a given rate to produce a given wattage
29-17- 8	Determining distance of earthquake from reporting station

MEASURING

Inquiry

3-17-11	Describing length in centimeters
3-17-11	Ordering specific time unit
3-19-13	Ordering simultaneous arrival; same start position--different times
3-22-14	Ordering simultaneous arrival; different start positions--same times
3-22-15	Ordering simultaneous arrival; different positions--different times
4- 7- 5	Constructing sentence model of measured changes in space and time
5- 2- 1	Demonstrating procedure for measuring radius of wheel
5- 2- 1	Describing rotational motion of wheel in revolution (ω)
5- 3- 2	Describing rotational motion of wheel in revolutions per minute
5- 3- 3	Constructing and measuring degrees per radian and radians per circle
5- 3- 3	Demonstrating measuring angles using degree scale protractor
5- 7- 6	Describing rotational speed of wheel in radians per minute
6-10- 6	Identifying and measuring relevant dimensions to solve a problem
6-10- 6	Describing translational and rotational motion in terms of frame of reference
10- 3- 4	Demonstrating the weighing of unknown using a known, string, and frictionless pulley in static and dynamic balance (zero acceleration)
10- 3- 4	Demonstrating the weighing of an object using single beam balance
10- 8- 5	Demonstrating the measurement of the force of friction in a pulley

10- 9- 6	Demonstrating the weighing of an object using pulley with measurable friction
10-16-11	Demonstrating vector representations of forces
10-16-11	Demonstrate when sin θ = zero that the moment of force is zero
10-16-12	Demonstrate zero acceleration when the sum of clockwise moments of force are equal to sum of counterclockwise moments
11-13- 4	Demonstrating procedure for determining ideal mechanical advantage (IMA)
11-13- 4	Demonstrating procedure for determining actual mechanical advantage when raising resistance (AMA) and when lowering it (ama)
14- 8- 1	Demonstrating procedures for measuring the acceleration of gravity
17-14- 4	Demonstrating procedure for measuring centripetal force
18-13- 4	Distinguishing when magnitude of acceleration vector of simple harmonic motion is zero and maximum and changing direction
18-14- 5	Distinguishing when velocity vector of simple harmonic motion is zero, maximum, and changing direction
19-20- 8	Demonstrating procedure for using an oscilloscope to graph the motion of a tuning fork
20-11- 8	Demonstrating the Blackburn double pendulum method of producing Lissajous figures to determine the period of the beat
21- 5- 4	Distinguishing translational velocity of an object by measuring time and distance
22- 8- 3	Determining procedure for measuring amount of energy changed to heat energy in a pulley system and then carrying out measurement
23- 4- 2	Describing comparison of calculated and measured values for v and h using equivalence of KE and PE in a falling plumet situation with spark tape record
23- 8- 3	Describing how measurements of v and h of a pendulum fit the model, $v^2 = 2gh$
24- 5- 1	Describing buoyant force acting on a submerged object

24-12- 3	Describing change in energy of position to energy of motion as a wooden block floats to surface
24-12- 4	Describing force needed to keep a block of wood submerged in water
24-12- 5	Describing predicted level of water on a block of wood when floated
25-11- 1	Describing water equivalent of the calorimeter in calories per degree centigrade
25-13- 2	Describing equivalence of calories and joules
25-18- 5	Describing heat of fusion of ice
25-21- 6	Describing heat of vaporization of water
26- 4- 2	Describing the horsepower an individual can develop running up a stairs by measuring vertical distance and time
26- 4- 3	Describing what one could earn per hour on the basis of his horsepower output if he were paid at the rate of 5 cents per kilowatt hour
27-11- 2	Describing micro ammeter reading for different frequencies
27-14- 3	Determining the natural frequency of a wire by producing Lissajous figures and reading audio generator frequency scale
27-14- 4	Determining resonant frequency of a wire
27-22-10	Determining node of vibrating wire by finding location where riders remain stationary
28-13- 5	Describing wave velccity on wave machine by measuring time and distance traveled
28-17- 6	Describing speed of soundwaves by using resonance of a closed tube
28-19- 7	Describing speed of sound waves in free space by using electronic equipment
28-11- 8	Describing speed of sound in metal by using free vibration and electronic equipment
28-24- 9	Determining length of a wave using electronic equipment
28-26-10	Determining frequency of micro waves

30-22-20	Demonstrating angle of incidence equal to angle of reflection
31- 4- 3	Describing the index of refraction by determining ratio of sine of angles
31- 7- 5	Describing effect of water depth on apparent elevation of object at the bottom
33- 2- 1	Determining gamma ray count using scalar with a Geiger tube
33-22- 6	Determining light intensity using light meter
34- 3- 7	Determining the combined amplitude for in-phase and 180° out of phase conditions using scope and audio generator
34- 8-12	Determining phase change at reflection for Lloyd's experiment
34-16-16	Determining the wavelength of micro waves by measuring the angle between the zero order ray and the first order ray and applying the formula, $\lambda = e \sin \theta$
34-24-21	Determining lines per inch in a diffraction grating by using a known wavelength light source and a spectrometer to measure angle between the zero order and first order spectrum
37-12- 3	Determining the stat-coulombs placed on ping-pong balls by measuring distance and determining the force

USING SPACE/TIME RELATIONSHIPS

Data Table Model

2- 9- 1	Distinguishing between time and space
2- 9- 1	Distinguishing distance change per time interval
2- 9- 1	Distinguishing time change per distance interval
2- 9- 1	Distinguishing number pairs
2- 9- 1	Distinguishing sequence and number pairs
2- 9- 1	Describing speed from space/time data table
2-11- 2	Recording number pairs of space and time
2-17-12	Demonstrating comparison of predicted and measured distance
4- 2- 1	Describing symbol of a sentence model
5- 3- 3	Recording relationships between radians, degrees, and revolutions
9- 4- 1	Recording data on v, t, and k

USING SPACE/TIME RELATIONSHIPS

Graph Model

2-11- 2	Distinguishing point plot of number pairs
2-11- 2	Distinguishing number pairs
2-12- 3	Distinguishing time change per distance interval
2-12- 3	Distinguishing distance change per time interval
2-12- 3	Distinguishing regular intervals
2-12- 3	Distinguishing limitations of limited plotted points for accurate interpolation
2-12- 3	Distinguishing limitations of limited plotted points for accurate extrapolation
3- 4- 1	Describing relative time that events took place in space
3- 4- 1	Describing why starting and finishing lines are parallel
3- 4- 1	Describing labeled points in time and space
3- 4- 1	Describing labeled points in time axis
3- 4- 1	Describing intervals on time axis
3- 4- 1	Describing labeled points on space axis
3- 4- 1	Describing line interval parallel to time axis
3- 4- 1	Describing line with constant slope as representing constant speed
3- 7- 2	Constructing line to represent average speed
3- 7- 2	Describing line with greater slope as representing greater speed
3- 7- 2	Constructing a line of given slope to determine time of an event in space
3- 7- 2	Distinguishing why x axis is used for time and y axis is used for space
3- 9- 3	Constructing a space/time graph

3- 9- 3	Describing direction of velocity by slope of line
3-12- 7	Distinguishing analogy between positive and negative x and y and positive and negative time and distance (quadrants)
3-14- 9	Describing positive change in slope as acceleration
3-17-12	Constructing a graph to make distance predictions by interpolating
3-19-13	Constructing a graph to make time predictions by interpolating
3-26-17	Describing slope of tangent
4- 7- 5	Constructing a graph to predict an event in time and space
5-10- 7	Constructing a graph model to predict cyclic phenomena in time and space
6- 4- 2	Constructing a graph model to solve a frame of reference problem for time at which an event will occur
6- 5- 3	Constructing graph model for a frame of reference problem to predict the direction and distance at which an event will occur
7- 4- 1	Constructing one dimensional time model
7- 5- 2	Constructing polar coordinates graph model to represent displacement in radians
7-10- 4	Distinguishing speed on three dimensional graph model
7-11- 5	Constructing three dimensional graph to represent tip of helicopter blade in time and space
8-18- 7	Distinguish vectors plotted on a coordinate axis graph model
9- 7- 6	Distinguishing inverse variation plot
9- 7- 8	Constructing inverse variation plot when one quantity has been reciprocated
9- 8- 9	Constructing inverse variation plot on log-log paper using logarithm method
10- 1- 1	Distinguishing graph plot of an object that is decelerating
10- 2- 3	Describing feature of graph line that would indicate zero acceleration

12- 5- 4	Demonstrating that the area under the line of a speed time graph represents distance traveled
33- 4- 3	Constructing graph of count rate of gamma rays and medium thickness
33-11- 7	Constructing graph of infrared energy received by sensor and water depth

USING SPACE/TIME RELATIONSHIPS

Sentence Model

4- 2- 1	Describing the code of a sentence model
4- 3- 2	Applying the formula for finding the area of a trapezoid to find the altitude
4- 3- 2	Transforming a sentence model
4- 7- 5	Constructing a sentence model to predict an event in time and space
4-12- 8	Constructing sentence model to prove two angles equal
4-14- 9	Applying formula for finding the area of a circle (two dimensional)
4-14- 9	Applying formula for finding the area of a closed cylinder (three dimensional)
4-15-10	Describing area of triangle in terms of at, t, and necessary number
4-15-10	Describing area of quadri-lateral in terms of V_o, a, and t
4-16-11	Describing sides of triangle using trigonometric functions
4-17-12	Applying pythagorean theorem to find unknown side of right triangle
5- 3- 2	Distinguishing simplified sentence model ($V = 2\pi r$ to $V = r$)
5-10- 7	Constructing sentence model to predict cyclic phenomena in time and space
6- 4- 2	Constructing sentence model to solve a frame of reference problem for time at which an event will occur
6- 8- 5	Constructing sentence model for a frame of reference problem to predict the direction and distance at which an event will occur
7-17- 5	Describing area in mixed dimensions
7-23- 8	Describing dimensions of unknown
8- 8- 2	Applying trigonometric functions to solve vector problems

8-18- 7	Applying rules for adding and subtracting vectors
9- 4- 1	Distinguishing number and dimensions for constant
9- 6- 4	Distinguishing inverse variation
13- 2- 1	Constructing analogous rotational motion sentence models from translational motion sentence models
15- 2- 1	Applying the formula, $s=\frac{1}{2}at^2$, to predict whether two objects released simultaneously from the same height will strike the ground at the same time if one is given an initial horizontal velocity
15-15- 6	Applying $s=\frac{1}{2}at^2$ and $D=vt$ to trajectory problem
15-21-11	Applying $t=\frac{2V_o \text{ Sin } \theta}{g}$ to predict angle of projection for maximum flight time
15-22-13	Applying $R=\frac{V_o^2 \sin 2\theta}{g}$ to predict angle for maximum horizontal distance
16-17-11	Applying $F=Ma$ to find the acceleration a given force will impart to a given mass
16-17-11	Applying $F=Ma$ to find force when acceleration and mass are given
16-17-11	Applying $F=Ma$ to find mass when acceleration and force are given
17- 4- 1	Applying geometry to prove two angles equal
18-21- 8	Constructing a general sentence model for the frequency beat of two objects that are each in simple harmonic motion
21- 2- 1	Describing dimensions of momentum in cgs, mks, and English system
22- 6- 1	Describing dimensions of the erg
22-24-13	Describing potential energy loss of a pendulum as it moves from position where all energy is potential to where it is all kinetic
22- 2- 1	Describing energy in gram centimeters and in ergs

23- 4- 2 Describing comparative rate of change of potential energy and potential energy of a freely falling object on a theoretical and measured basis

USING SPACE/TIME RELATIONSHIPS

Diagram Model

5- 3- 3	Constructing an angle equal to one radian by measuring off the length of a radius along the edge of a disc
5- 3- 3	Constructing radians to determine the approximate number per disc
6-10- 6	Describing distance frame of reference prediction from analysis of diagram model
8- 3- 1	Constructing a scale drawing of vectors to solve a problem
9- 6- 3	Distinguishing inverse variation of pulley radius and rotational speed when rotated by a belt moving at a constant speed
11- 1- 1	Distinguishing ratios of speed in pulley system
12- 3- 1	Distinguishing series of distances fallen each second in order to extrapolate others
18-17- 7	Describing phase and amplitude of simple harmonic motion
22-23-12	Constructing a diagram to show that the center of gravity of an ideal machine does not rise or fall
28- 7- 2	Describing phase difference between two points
30- 7- 1	Constructing a diagram of standing waves on the Bell Wave Machine for reflection at a free and at a clamped end
32- 8- 4	Constructing diagram of light waves passing through and leaving a double convex lens

USING SPACE/TIME RELATIONSHIPS

Descriptive Model

21- 4- 3 Describing large force developed by a hammer

21- 4- 3 Describing how to prevent the sting of a caught baseball

21- 9- 7 Describing why momentum of universe will remain constant

USING SPACE/TIME RELATIONSHIPS

Inquiry

3-17-12 Constructing laboratory check of interpolated distance prediction (from graph)

3-19-13 Constructing laboratory check of starting times and distance at which objects traveling at different rates will have moved the same distance (from graph)

3-22-14 Constructing laboratory check of predicted starting points if objects traveling at different rates are to arrive at a given distance at the same time (from graph)

3-22-15 Constructing laboratory check of predicted different starting points and different times for objects traveling at different rates to be together at a given time (from graph)

4- 7- 5 Demonstrating validity check of predicted event in time and space (from sentence)

5- 2- 1 Demonstrating laboratory verification of sentence model ($V=2\pi rw$)

5- 6- 5 Demonstrating validity check of transformed sentence model ($W=\frac{V}{r}$)

6- 3- 1 Demonstrating validity check of frame of reference sentence model

6- 7- 4 Demonstrating validity check of frame of reference graph model used to predict direction and distance at which an event will occur

10- 3- 4 Distinguishing weight of bucket that is in dynamic balance (frictionless system)

10- 8- 5 Distinguishing force of friction by utilizing dynamic balance

10- 9- 6 Distinguishing weight of object by utilizing dynamic balance (friction system)

12-16-10 Demonstrating validity check of $s=v_0t+\frac{1}{2}at^2$

13- 4- 3 Applying the rotational motion sentence model, $W=\sqrt{2\alpha\theta}$

13- 4- 4	Applying the rotational motion sentence models, $\theta=w_0t+\frac{1}{2}\alpha t^2$ and $\theta=w_0t-\frac{1}{2}\alpha t^2$
14- 8- 1	Measuring the acceleration of gravity
15- 3- 2	Constructing laboratory check of prediction that two objects released simultaneously from the same height will strike the ground at the same time if one is given an initial horizontal velocity
18-10- 3	Describing the acceleration of a pendulum as it passes through its equilibrium point
18-13- 4	Describing where magnitude of acceleration is zero and maximum for simple harmonic motion
18-13- 4	Describing where acceleration changes direction for simple harmonic motion
18-14- 5	Describing where velocity is zero and maximum for simple harmonic motion
18-14- 5	Describing where velocity changes direction for simple harmonic motion
18-22- 9	Constructing laboratory check of frequency beat equation, $f_b=f_f-f_s$
19- 3- 2	Constructing laboratory check of velocity model, $V=V_m\cos\theta$, for simple harmonic motion
19- 8- 5	Constructing laboratory check of acceleration models of simple harmonic motion
19-16- 7	Constructing position graph plot of simple harmonic motion using shadow graph method and also using the swinging pendulum
19-16- 7	Constructing a phase difference plot on a graph of position
19-20- 8	Constructing graph of motion of the prong of a tuning fork using an oscilloscope
20- 3- 2	Constructing a laboratory check for a sentence model for the period of a mass oscillating on a spring
23- 8- 3	Demonstrating how well the model, $V^2=2gh$, fits a swinging pendulum by "shooting tapes" with the spark machine
24-14- 7	Describing energy transfer for bouyancy of rock suspended in water and then allowed to sink to the bottom

26- 4- 3	Demonstrating the horse power one can produce by running up a flight of stairs and computing change in potential energy per time
27-14- 3	Describing natural frequency of a wire
27-14- 4	Distinguishing resonant frequency of a wire
28-12- 4	Constructing a laboratory check of formula, $PE=\frac{1}{2}KX^2$, for a spring by "shooting a tape" using spark apparatus
28-13- 5	Distinguishing the velocity of a wave on the Bell Wave Machine by measuring time and distance, (28-17-6) by using resonance of a closed tube, (28-19-7) by using electronic equipment to measure velocity of sound in free space, and (28-21-8) by using free vibration to measure speed of sound in metal
30- 9- [illegible]	Describing phase change of wave at boundary
30-16- 6	Describing real point source distance and virtual point source distance of light waves striking plane mirror
30-22-19	Demonstrating that angle of incidence is equal to angle of reflection
31- 6- 4	Describing why sun is seen before actually rising or after setting (refraction)
31- 7- 5	Describing effect water depth has on apparent elevation of object on the bottom
31-16- 9	Describing critical angle for glass and air boundary
32-18-13	Describing image size produced by converging and diverging mirror
33-19- 5	Describing how a sealed beam headlight diverges light slightly
33-22- 6	Describing how light intensity decreases with distance
34- 1- 1	Describing amplitude due to reinforcement
34- 1- 2	Describing amplitude due to interference
35-11- 8	Describing polarization by reflection
35-19-10	Describing orientation of the reflection of a reflected image

USING NUMBERS

Data Table Model

2- 9- 1	Identifying and naming number pair (sets) from data table model
2- 9- 1	Demonstrating interpolation from data table model
2- 9- 1	Demonstrating extrapolation from data table model
2- 9- 1	Demonstrating relating speed to S/T data table model
2-11- 2	Describing number pairs by recording on data table model
3-17-11	Describing distance measured in centimeters
3-17-12	Comparing predicted and measured distance per given time
15- 7- 4	Demonstrating procedure for making a table of y values for the equation, $y=Kx^2$, when values for x and the value of K are given
16- 1- 1	Recording components of forces (vectors)
27- 8- 1	Describing micro ammeter reading
29-17- 8	Describing distance at which earthquake had occurred from receiving station
37-10- 1	Describing values of length, displacement, displacement per length, force, distance, and $\frac{Fd^2}{q_1q_2}$ for statics

USING NUMBERS

Graph Model

2-11- 2	Identifying and naming number pairs from coordinate axis graph model
2-12- 3	Demonstrating interpolation from graph model data
3- 4- 1	Describing slope of line/speed relationship from coordinate axis graph model
3- 4- 1	Describing number pairs from coordinate axis graph model
3- 4- 1	Describing intervals on coordinate axis graph model
3- 7- 2	Demonstrating the finding of average speed from coordinate axis graph model
3- 9- 3	Constructing a two dimensional graph model
3-10- 4	Describing what positive, zero, and negative slope represents on graph model
3-11- 6	Describing direction of positive or negative velocity
3-14- 8	Describing negative time plot on coordinate axis graph model
3-14- 9	Describing curved line/acceleration relationship on graph model
3-19-13	Constructing graph to predict an event in time and space
3-26-17	Describing tangent line/curved line relationship on graph model
4- 7- 5	Demonstrating developing graph models to solve problems
7- 5- 2	Describing rotational motion using polar coordinates
7- 6- 3	Describing rotational motion on three dimensional graph model
9- 7- 6	Describing graph line for inverse variation
9- 7- 8	Demonstrating using graph to check variation
9- 8- 9	Demonstrating logarithm method of graphing

12- 4- 3	Describing area under the graph line of a speed/time plot as representing distance traveled
15- 7- 4	Demonstrating shadow graphing of an accelerating object
22-21- 9	Describing equivalent areas under graph lines

USING NUMBERS

Sentence Model

4- 2- 1	Describing code of sentence model
4- 3- 2	Demonstrating procedure for finding unknown using sentence model
4- 5- 3	Demonstrating transformation of sentence model
4- 7- 5	Demonstrating developing sentence models to solve problems
7-17- 5	Demonstrating algebraic treatment of mixed units
7-20- 7	Demonstrating dimensional analysis
8-18- 7	Demonstrating subtraction of vectors
9- 4- 1	Identifying and naming number and units of constant
9- 5- 2	Demonstrating converting constant to number value only
9- 6- 3	Describing direct variation
9- 6- 3	Describing inverse variation
9-14-12	Demonstrating solving variation problems
12- 3- 2	Describing a series of distance numbers for successive seconds for an object starting at rest and accelerating uniformly
12-20-12	Demonstrating procedure for analyzing a quadratic using general quadratic equation
13- 2- 1	Demonstrating procedure for deriving analogous rotational motion models from translational motion models
21- 2- 1	Describing dimensions for momentum and impulse using the Newton and poundal force dimensions
21- 3- 2	Describing dimension for momentum and impulse using the absolute mass dimensions of slugs
21- 8- 5	Describing the relationship between the momentum of two masses in a system that have the same force acting on them by developing a sentence model to equate the two
22- 6- 1	Describing dimensions of the erg

22-22-10	Describing machine efficiency
22-24-13	Describing potential energy loss of pendulum that has fallen a given vertical distance
23- 2- 1	Demonstrating procedure for calculating energy in gram centimeters and ergs
31-10- 6	Describing apparent elevation of an object in water
31-12- 8	Describing critical angle for a water air boundary

USING NUMBERS

Diagram Model

4-12- 8	Demonstrating two angles to be equal using geometric proof
4-14- 9	Demonstrating finding surface areas of two and three dimensional objects
4-16-11	Describing trigonometric functions of an angle
4-16-11	Describing trigonometric functions for side length
4-17-12	Demonstrating finding sides of right triangle using pythagorean theorem
8- 3- 1	Demonstrating solving vector problems by scale drawing
8- 8- 2	Demonstrating solving vector problems using trigonometric functions
10-13-10	Describing direction of force of moment of force using sine function
11- 1- 1	Describing ratios of masses to balance system
24-12- 3	Describing energy of position
24-12- 4	Describing downward force need to keep wooden block submerged
24-12- 5	Describing waterline on floating block
28- 7- 1	Describing phase of a wave
28- 7- 2	Describing phase difference between two points on successive waves in degrees and radians
30-16-16	Describing relationship of actual point source distance to reflecting front and virtual point source to same front
30-22-20	Describing angle of incidence equal to angle of reflection

USING NUMBERS

Descriptive Model

USING NUMBERS

Inquiry

3-17-11	Describing measured linear metric units
5- 2- 1	Demonstrating laboratory verification of sentence model
5- 3- 3	Demonstrating construction of a radian
5- 3- 3	Identifying and naming number of radians per revolution
23- 8- 3	Distinguishing that $V^2=2gh$ fits the pendulum at its equilibrium position
24- 5- 1	Describing buoyant force acting on a submerged object
25-11- 1	Describing the water equivalent of a calorimeter
25-13- 2	Describing relationship of calories to joules
25-15- 3	Describing specific heat of a metal
25-18- 5	Describing heat of fusion of water
25-21- 6	Describing heat of vaporization
26- 4- 3	Describing the horsepower an individual can produce
26- 4- 3	Describing dollar value of horsepower produced
28- 8- 5	Describing electrical input
28- 8- 5	Describing mechanical output
28- 8- 5	Describing energy converted to heat
28- 8- 5	Describing efficiency of system
27-14- 3	Describing natural frequency of a wire
27-14- 4	Describing comparison of natural and resonant frequency of a wire
27-17- 6	Describing comparison of derived and experimental results
28-13- 5	Describing velocity of a wave on wave machine
28-17- 6	Describing velocity of sound waves in air

28-21- 8	Describing velocity of sound waves in a metal rod
28-26-10	Describing frequency of micro waves
29- 5- 2	Describing relationship between amount spring is stretched and wave velocity
32- 8- 4	Demonstrating that the sum of the reciprocals of the object distance and image distances remain constant
33-10- 6	Describing difference between predicted and measured count of gamma rays using scalar
33-11- 7	Describing infra red waves reaching sensor for different depths of water
35-13- 9	Describing a mathematical analysis to produce the necessary models to determine the angle of incidence for the most effective polarization of light

COMMUNICATING

Data Table Model

2- 9- 1	Describing interpolated distance
2- 9- 1	Describing extrapolated time
2- 9- 1	Describing speed in miles per hour
2-11- 2	Describing number pairs
2-12- 3	Describing interpolated time
3-17-11	Describing measured distance
3-17-12	Comparing measured and predicted distance
3-19-13	Describing predicted release time
3-23-16	Describing altitude at different times
4- 2- 1	Describing symbolic code of diagram
5- 3- 3	Describing relationships between radians, degrees, and revolutions
9- 4- 1	Describing measured time, the constant of variation, and computed velocity
9- 6- 4	Describing measured radius and rotational speed and computed constant of variation
15- 7- 4	Describing values of Y for equation, $-Y=Kx^2$, when values of x and K are given
16- 1- 1	Describing force vector x and Y components
16-10- 9	Describing dimensions of newton, dyne, and poundal
19- 2- 1	Describing velocity of oscillating shadow at thirty degree intervals if it is 10 $\frac{cm}{sec}$ at 0° phase position
19- 2- 1	Describing significance of positive and negative signs of phase velocity

20-14-10	Constructing a table of x and y values for different values of θ for Lissajous figure
22-25-14	Describing energy dimensions from force and distance dimensions
27-11- 2	Describing micro ammeter readings
29-21- 9	Describing relationship between molecular weight of gasses and the velocity of sound in these gasses for a constant temperature

COMMUNICATING

Graph Model

2-12- 3	Describing interpolated time and distance
3- 4- 1	Describing the relationship of positive slope of line to speed
3- 4- 1	Describing lines parallel to time axis
3- 4- 1	Describing number pair points
3- 4- 1	Describing points on time axis
3- 4- 1	Describing time intervals
3- 4- 1	Describing points on distance axis
3- 4- 1	Describing distance intervals
3- 7- 2	Constructing a line to represent average speed
3- 9- 3	Constructing lines with positive, zero, and negative slope
3-10- 4	Describing that a line with zero slope represents zero speed
3-11- 6	Describing that positive velocity represents positive direction
3-11- 6	Describing that negative velocity represents negative direction
3-14- 8	Constructing a line to represent positive distance in negative time
3-14- 9	Describing change of slope relationship to changing speed
3-17-12	Constructing a space/time graph
3-26-17	Describing tangent to changing slope
5-10- 7	Describing a cyclic phenomena in time and space
6- 4- 2	Describing frame of reference
7- 5- 2	Describing race using polar coordinates

7-11- 5	Describing motion of helicopter blade tip in three dimensions in time and space
9- 7- 7	Naming plot of inverse variation as a hyperbola
9- 7- 8	Constructing graph plot of inverse variation where one quantity has been reciprocated
9- 8- 9	Constructing graph on log-log graph paper using logarithm method
10- 1- 1	Describing graphs with titles
12- 5- 4	Describing area under graph line of speed and time graph represents distance traveled
15- 7- 4	Describing change of shape of curve if V_x increases so that K decreases in the equation, $K=\frac{g}{V_x^2}$
19-11- 6	Constructing a graph of displacement and phase angle of simple harmonic motion
20-14-10	Constructing a graph of x and y values of θ of Lissajous figure
22-21- 8	Describing how a portion of the area of a graph was drawn to represent energy changed to heat energy
22-21- 9	Describing area of one plot to be equal to area of another plot on same axis

COMMUNICATING

Sentence Model

4- 5- 3	Describing process of transforming sentence model
4-10- 6	Constructing a sentence model to predict an event in time and space
5-10- 7	Describing a cyclic phenomena in time and space
6- 4- 2	Describing frame of reference
7-17- 5	Describing dimensions in mixed units
7-23- 8	Describing predicted dimensions of unknown
9- 7- 6	Describing predicted inverse variation
12- 4- 3	Describing a discovered model for a series of distance numbers for the model $a=n\frac{cm}{sec^2}$
13- 2- 1	Describing analogous rotational motion models from translational motion models
19-11- 6	Describing acceleration of simple harmonic motion for any phase angle by developing the model
21- 2- 1	Describing dimensions of momentum and impulse developed from the Newton, the poundal and the slug
21- 8- 5	Describing a developed model relating masses and velocities
22- 6- 1	Describing dimensions of an erg from those of the dyne
22-22-10	Describing calculations of machine efficiency

COMMUNICATING

Diagram Model

4- 2- 1	Describing symbolic code of diagram
4-12- 8	Describing two angles to be equal using geometric proof
4-14- 9	Describing procedure for finding area of circle, closed cylinder, and cube
4-16-11	Describing trigonometric functions of an angle
5- 3- 3	Describing characteristics of a radian
8- 3- 1	Describing the magnitude of vectors by use of scale drawing
8-11- 3	Constructing vector components
8-11- 4	Describing procedure used to draw vector components
11-17- 7	Describing procedure for predicting Ideal Mechanical Advantage of an inclined plane
12- 3- 1	Describing predicted distance of fall for tenth second from distance number pattern for first four seconds
18-15- 6	Describing phase angles of simple harmonic motion
18-17- 7	Describing amplitude and phase difference of simple harmonic motion
20-14- 9	Describing how Lissajous rectangle can be used to compare amplitudes of two simple harmonic motions
22-23-12	Constructing a diagramed system to scale
22-23-12	Describing by construction that the center of gravity of a cart and bucket system remains at the same level in the gravity force field as the cart moves up incline and bucket moves down
29-16- 7	Describing where earthquake took place by analyzing scale diagram model of intersecting circles
30- 7- 1	Constructing a diagram of standing waves on a Bell Wave Machine at a free and at a clamped end

34-14-15 Describing a wave front as being of a first order

COMMUNICATING

Descriptive Model

9- 5- 2	Describing process of changing constant with number and dimensions value to number value only
9-20-18	Describing reasoning sequence in solving variation problem
10-16-11	Describing a situation where moment of force is zero because sine θ is zero
11- 9- 2	Describing conditions under which resistance would move down with zero acceleration if effort force were zero in pulley system
11- 9- 2	Describing conditions under which resistance would move down with zero acceleration if negative effort force were applied in pulley system
12- 3- 2	Describing a number series for distance each second for an object accelerating at the rate of three centimeters per second per second
12- 4- 3	Describing theoretical velocity of an object that was dropped freely for eighty-one feet
16-15- 8	Describing some invented force dimensions
16-16-10	Describing slug in terms of its dimensions
16-22-14	Describing conversion of gravitational units of force to absolute units of force
16-23-15	Describing force in g's of force
17-18- 7	Describing how an object can be accelerated toward the center of the earth and yet move in an elliptical orbit around the earth
18-13- 4	Describing when acceleration of simple harmonic motion changes direction and when magnitude of acceleration is zero and maximum
18-14- 5	Describing when velocity of simple harmonic motion changes direction and when it is zero and maximum
21- 4- 3	Describing how to prevent the sting of caught baseball

21- 9- 7	Explaining the statement that "The momentum of the universe will never change but always remain constant."
22- 7- 2	Describing predicted series of events
22- 8- 3	Describing theoretical procedure for measuring energy of motion changed to heat energy in a system
24-17-10	Describing missing energy in logical presentation
24-17-11	Describing how a balloon can change potential energy to kinetic energy as it rises
29-15- 6	Describing relationship between longitudinal and transverse wave amplitudes in deep and shallow water
31-19-10	Demonstrating that a 90 degree prism made of glass produces total reflection when mounted so that rays entering and leaving are perpendicular to one of faces of prism
32- 5- 3	Describing how a chromatic lenses color correct from reading descriptive material
34- 2- 5	Describing impedance requirements to produce two reflected wave pulses that are 180° out of phase
34- 8-11	Describing a formulated rule for the number of half wave length differences that produce destructive interference--constructive reinforcement
34-12-14	Describing a small distance in angstroms
34-20-23	Describing hypothesis to explain color production
34-33-27	Describing spectrum of colors produced by a soap bubble by drawing an analogy between light waves and micro waves
35-23-14	Describing organized presentation on polarization of light that could be given using two polaroid disks and a light source
36-10- 6	Describing why spectral lines become wider with increase in temperature by applying Doppler's Principle

COMMUNICATING

Inquiry

6- 7- 4	Describing validity check of model
9- 8- 9	Presenting a report of a project
10- 3- 4	Describing observations of static and dynamic balance of frictionless pulley system
10- 8- 5	Describing project data on finding force of friction in pulley
10- 9- 6	Describing project data on finding weight of object using a pulley with friction and utilizing dynamic balance
10-11- 7	Describing predictions and justification of prediction of weight that will produce zero acceleration of frictionless pulley system
10-11- 8	Describing comparison of predicted and laboratory results of weight that will produce zero acceleration of frictionless pulley system
10-17-13	Describing predicted moment of force that will produce zero acceleration of frictionless pulley system
11-13- 4	Describing data and analysis of data of a four rope pulley system for Ideal Mechanical Advantage, Actual Mechanical Advantage, and actual mechanical advantage
11-20- 8	Describing data and analysis of data of a cart on an inclined plane for Ideal Mechanical Advantage, Actual Mechanical Advantage, and actual mechanical advantage
14- 8- 1	Describing data and analysis of data in determining acceleration of gravity
15- 3- 2	Describing observed resulting time of fall of an object projected horizontally and one dropped at the same moment
16- 1- 1	Describing data analysis of force vectors that indicates zero acceleration of a point
16-11- 3	Describing accelerating force in grams
22-12- 5	Describing observations of a weighted wheel on an inclined plane

25-11- 1	Comparing results of measurements of calories per degree change in temperature of calorimeter
27- 8- 1	Describing mechanical resonance of a spring by drawing a resonance curve from measured amplitude and frequency difference
27-14- 4	Describing relationship discovered when comparing resonant and natural frequency of a wire
29- 5- 2	Describing relative time for a wave to travel down a spring for two different lengths
30-12- 9	Describing evidence to substantiate a conclusion
30-13-11	Describing analogous situations
30-17-17	Explaining the cause of an observation
31-16- 9	Describing observed critical angle of a glass air boundary
34-11-13	Describing observations by completing a diagram of straight line water waves passing through openings between paraffin blocks
35- 1- 1	Describing evidence that might be used to classify electromagnetic waves as transverse or as longitudinal
35-20-13	Describing hypothesis formulated for "red sunset" from evidence collected

INVESTIGATING

Data Table Model

2- - Inquiring systematically into the construction and use of data table models to promote their construction and use throughout the course as a primary method of organizing and communicating data

INVESTIGATING

Graph Model

3- - Inquiring systematically into the construction and use of graph models to promote their construction and use throughout the course as a primary method of organizing and communicating related data that can be easily interpreted

INVESTIGATING

Sentence Model

4- - Inquiring systematically into the construction and use of sentence models to express relationships and solve for unknowns to promote their use throughout the course

INVESTIGATING

Diagram Model

4- - Inquiring systematically into the construction and use of diagram models to facilitate their construction, labeling, interpretation, and use of related sentence models throughout the course

INVESTIGATING

Descriptive Model

3- - Inquiring systematically into the interpretation and construction of descriptive models to pass and receive information and to relate it to other modes of communication throughout the course

INVESTIGATING

Inquiry

5- 2- 1	Reporting how nearly the sentence model, $V=2\pi rw$, fits the data collected for different gear driven step pulleys
5- 3- 3	Constructing, defining, measuring and describing radians per circumference and revolution and radians per degrees
5- 6- 5	Reporting how nearly the models, $V=2\pi rw$ and $V=rw$, that are transformed to models for w fit the data collected for different gear driven step pulleys
5- 7- 6	Reporting on theoretical and laboratory solution of a problem to determine position and time at which markers on two different sized pulleys will again be together if they are driven by string belts attached to different sized gear driven pulleys revolving at the same rate
6- 3- 1	Reporting how the sentence model, $t=\frac{300\text{ cm}}{V_{12}+V_{32}+V_{42}}$, fits a frame of reference problem
6- 4- 2	Reporting results of solving a problem using a frame of reference in developing a sentence model and a graph model
6- 7- 4	Reporting results of checking the validity of a general graph model solution of a frame of reference problem
7- -	Constructing one, two, and three dimensional graph models from descriptive models
7- -	Reporting operations with numbers and dimensions, the selection of dimensions, and the use of dimensional codes
8- -	Reporting operations with vectors and vector components using algebra and trigonometry
9- -	Reporting experiences with variables, constants, direct and inverse variation, graph models of direct and inverse variation - first power of variables, reciprocals, and logarith functions, and multiple variation
10- -	Reporting experiences with static and dynamic balance, balanced torques or moments of force, and center of gravity as they relate to zero acceleration

11- - Reporting experiences with determining the ideal mechanical advantage of a four rope pulley system by the zero acceleration and relative distance methods and the ideal and actual mechanical advantages of a single movable pulley, an inclined plane, and a compound machine

12- - Reporting experiences with sentence and graph models and the checking of models in the laboratory for initial velocity and constant positive acceleration and initial velocity and constant negative acceleration

13- - Describing analogous rotational motion sentence models developed from translational motion sentence models and reporting experiences checking and applying the sentence models, $W= 2 \quad \theta$, $\theta=W_0t+\frac{1}{2}\ t^2$, and $\theta=W_0t-\frac{1}{2}\ t^2$

14- - Reporting experiences with various procedures used to measure the acceleration of gravity near the surface of the earth

15- - Reporting experiences with verifying sentence models for the motion of an object projected horizontally

16- - Reporting experiences with a check of the variation for a constant accelerating mass and for a constant accelerating force

17- - Reporting experiences verifying the sentence model for centripetal acceleration

18- - Reporting experiences with shadow graphing the velocity vector and the acceleration vector of the shadow of a revolving peg and with shadow graphing the phase relationship between two objects in simple harmonic motion with the same period and two with different periods to show beats

19- - Reporting experiences with checking velocity and acceleration models for simple harmonic motion

20- - Reporting experiences with checking the model for the period of a mass oscillating on a spring and with comparing the frequencies of two pendulums and two tuning forks using Lissajous Figures

21- - Reporting experience with internal forces and momentum

22- - Reporting experiences with energy of position and energy of motion

23- - Reporting experiences with equating loss of energy of position with a gain in energy of motion and with checking the equivalence of loss of energy of position and gain in energy of motion for a pendulum bob

24- - Reporting experiences with the buoyant force acting on a metal block submerged in water (Archimede's Principle)

25- - Reporting experiences with determining the water equivalent of a calorimeter, determining the relationship of the Joule and calorie, determining the specific heat of a metal, determining the temperature of a hot nail, determining the heat of fusion, and determining the heat of vaporization

26- - Reporting experiences with measuring the watt and horsepower output of muscles and the efficiency of a small electric motor

27- - Reporting experiences with forced vibration and resonance

28- - Reporting experiences with verifying the sentence model, $PE=\frac{1}{2}Kx^2$, with a mass on a spring and with measuring velocity of waves on the Bell Wave machine, velocity of sound waves in a closed tube, in open space, and in metal; and the frequency of a sound source and of micro waves

29- - Reporting experiences with factors that determine wave velocity

30- - Reporting experiences with impedance and reflection of waves

31- - Reporting experiences with measuring the critical angle and index of refraction

32- - Reporting experiences with spherical aberration and lens and mirror images

33- - Reporting experiences with absorption, reflection and spreading of waves

34- - Reporting experiences with interference and reinforcement of waves

35- - Reporting experiences with polarization and double refraction of waves and measuring Brewster's angle for glass

36- - Reporting experiences with string belts to simulate Doppler's Principle

37- - Reporting experiences with electrostatics in checking Coulomb's Law

INFERRING

Data Table Model

2- 9- 1 Describing expected data pairs from those given

2- 9- 1 Describing expected speedometer reading from time and distance data pairs

2-12- 3 Recognizing that inferences are based on assumptions

9- 6- 5 Constructing inferences from observations of data

INFERRING

Graph Model

2-12- 3	Describing expected data pairs from those plotted
2-12- 3	Recognizing that inferences are based on assumptions
3-10- 4	Ordering inference that zero slope represents zero speed if the slope of a graph line represents speed
3-14- 9	Ordering inference that a line with positive changing slope indicates an object has speeded up
3-26-17	Ordering inference of what caused change in slope of line

INFERRING

Sentence Model

7-23- 9 Deriving dimensions for an unknown

9- 4- 1 Constructing inferences from observations (inverse or direct variation)

INFERRING

Diagram Model

5- 3- 3 Ordering inference of radians per circle by knowing relationship of radius to radian and radius to circumference

6-10- 6 Constructing inference from observation

5-10- 6 Describing expected outcomes of future observations based on inferences formulated and tested by individual

INFERRING

Descriptive Model

2-12-13 Identifying inferences stated by others

10-13-10 Distinguishing that inferences may need to be altered

INFERRING

Inquiry

3-19-13 Constructing inferences from observations

5- 7- 6 Describing expected outcomes of future observations based on inferences formulated and tested by individual

30-22-20 Constructing a laboratory check of an inference

35-11- 8 Describing inference that reflected light is polarized from observations made through polaroid lens

CLASSIFYING

Data Table Model

2-11- 2 Arranging number pairs on data table model

3-17-12 Categorizing distance as predicted and measured

8- 6- 4 Distinguishing between direct and inverse variation

CLASSIFYING

Graph Model

3- 7- 2	Assigning time to X axis
3- 7- 2	Assigning distance to Y axis
3- 9- 3	Assigning t_0 and d_0 as origin
3- 9- 3	Assigning positive slope positive speed
3- 9- 3	Assigning negative slope negative speed
3- 9- 3	Assigning zero slope zero speed
3-12- 7	Assigning positive and negative quadrants for time and space
3-23-16	Assigning an object a certain speed
3-26-17	Assigning an object traveling towards the earth as having negative velocity

CLASSIFYING

Sentence Model

4- 2- 1	Assigning equivalences
4- 2- 1	Assigning representative symbols
4- 3- 2	Ordering equations to solve for unknown
4-16-11	Ordering trigonometric functions
21- 2- 1	Assigning dimensions to momentum and impulse based on the Newton and poundal as absolute units of force
21- 3- 2	Assigning dimensions to momentum and impulse based on the absolute mass dimensions of slugs

CLASSIFYING

Diagram Model

4- 2- 1	Assigning representative symbols
4-12- 8	Assigning equal value to angles on basis of geometric proof
8-11- 5	Distinguishing between horizontal and vertical vector component
8- 6- 3	Distinguishing between direct and inverse variation
18-15- 6	Distinguishing among phase angles

CLASSIFYING

Descriptive Model

2- - Categorizing models

8- 3- 1 Distinguishing between vector and scalar quantities

12- 2- 2 Distinguishing between acceleration and deceleration

16-16- 9 Distinguishing between Newton, dyne, and poundal

CLASSIFYING

Inquiry

3-17-11	Assigning numbers to object on the basis of speed
10-16-12	Distinguishing between clockwise and counter clockwise moments of force
11-13- 4	Distinguishing among Ideal Mechanical Advantage, Actual Mechanical Advantage, and actual mechanical advantage
27-14- 4	Distinguishing between resonant and natural frequency of a wire
34- 5- 8	Distinguishing between reinforcement and interference of waves
35-20-12	Distinguishing direction of polarization of light

INTERPRETING DATA

Data Table Model

2- 9- 1 Describing space and time number pairs as miles per hour

15- 7- 4 Describing corresponding values of y for given values of x for sentence model, $-y=Kx^2$, where K is equal to 2

25-15- 3 Describing general relationship of specific heat of water to those of other substances listed in a handbook

29-17- 8 Describing distance from a reporting station that an earthquake occurred by knowing velocities of longitudinal and transverse waves and difference in arrival time

29-21- 9 Describing relationship between the molecular weight of gases and the velocity of sound in these gases for a constant temperature

29-21-10 Describing how a change in velocity of sound in a gas that has changed temperature supports the idea that a group of molecules are the vibrating element in sound waves

INTERPRETING DATA

Graph Model

3- 4- 1	Describing positive slope of line and speed relationship on a space and time graph
3- 4- 1	Describing line with zero slope as representing change in time with no change in distance
3- 4- 1	Describing points plotted on space and time graph
3- 4- 1	Describing intervals of time and space on graph
3- 4- 1	Describing line with constant slope as representing constant speed
3-14- 9	Describing line with positive changing slope as indicating the object has speeded up
3-17-12	Constructing a graph of space and time changes with the purpose of interpreting data to formulate predictions,
3-25-17	Describing space and time plot in fourth quadrant as representing negative velocity
4- 7- 5	Constructing graph model of interpreted relationships
4-10- 6	Identifying relationships of space and time in one graph that permit the construction of one for a new set of conditions
7-10- 4	Describing space and time relationships on a three dimensional graph
9- 7- 5	Constructing graph showing inverse variation
9- 8- 9	Constructing graph of inverse variation using logarithm method
22-21- 8	Describing how the area under a graph line was determined and drawn
22-21- 9	Equating the areas of two different shaped plots on a coordinate axis graph
22-22-10	Calculating the efficiency of a machine from a plot of energy gain and energy expended
23- 4- 2	Describing the velocity and height of an object from a spark tape record to determine PE and KE

INTERPRETING DATA

Sentence Model

4- 2- 1	Describing relationships programmed into sentence model
4- 3- 2	Identifying unknown by programming sentence model
4- 5- 3	Transforming sentence models
4- 7- 5	Constructing sentence model of interpreted relationships
7-23- 8	Identifying dimensions of unknowns
8-11- 5	Identifying vector resultant
9- 4- 1	Identifying the constant of variation
23- 8- 3	Describing the velocity and height of a pendulum from a spark tape record to determine how well the model, $V^2=2gh$, fits the pendulum
27-20- 8	Demonstrating that the model, $n=\frac{1}{2L}\sqrt{\frac{F}{M}}$, applies to a set of data by selecting a set of data

INTERPRETING DATA

Diagram Model

4-12- 8	Identifying two angles to be equal utilizing geometric proof
6-10- 6	Identifying relationships to form frame of reference predictions
8- 3- 1	Constructing vectors to scale to determine resultant
12- 3- 1	Identifying number pattern of distance per second for an object accelerating uniformly
18-15- 6	Describing phase angle of simple harmonic motion
22-12- 5	Describing energy changed to heat energy in an unbalanced zero accelerating pulley system that has the masses move a specified distance
22-23-12	Constructing cart, inclined plane, and mass to scale to demonstrate that for an ideal machine the center of gravity of cart and mass does not change in the gravity force field as the cart moves up or down and the mass moves down or up
24-14- 7	Describing energy lost by mass of object submerged in water as energy gained and lost by water displaced and overflowed from container
24-17-10	Describing missing energy in logical analysis of a series of diagrams
28- 7- 1	Describing phase of wave in degrees and radians
28- 7- 2	Describing phase difference of points on wave in degrees and radians
29-16- 7	Describing location of an earthquake by noting where arcs from three reporting stations intersect

INTERPRETING DATA

Descriptive Model

3- 9- 3	Constructing a space and time graph from a descriptive model
3-11- 6	Describing direction of positive and negative velocity
24-12- 3 - 4 - 5	Describing energy of position changed to energy of motion, the downward force needed to keep wooden block submerged, and the level of the water line when it floats from known mass and volume
24-13- 6	Describing potential energy lost by object sinking in water that has reached terminal velocity as changing to heat energy
31- 6- 4	Describing observation of why the sun can be seen before sunrise tne after sunset

INTERPRETING DATA

Inquiry

5- 2- 1	Verifying formula, $V=2\pi rw$
6- 3- 1	Verifying formula, $t=\frac{300\text{ cm}}{V_{12}+V_{32}+V_{42}}$
6- 7- 4	Checking validity of a graph model
6-10- 6	Verifying frame of reference predictions
9- 6- 3	Identifying inverse variation
9- 6- 4	Identifying constant of variation
10- 3- 4	Identifying dynamic and static zero acceleration
10- 8- 5	Identifying the force of friction in a pulley
10-11- 8	Identifying weight of object using pulley with friction, known weights, and dynamic balance
10-17-13	Identifying unknown weight that would produce zero acceleration in a situation of moments of force
11-13- 4	Identifying Ideal Mechanical Advantage, Actual Mechanical Advantage, and actual mechanical advantage of a pulley system
11-22- 9	Identifying relationship of Ideal Mechanical Advantage of inclined plane and IMA of wheel and axle in a compound machine
12-11- 7	Verifying formula, $a=\frac{2s}{t^2}$
12-13- 8	Verifying sentence models, $V=\sqrt{2as}$ and $V=at$
14- 8- 1	Identify acceleration of gravity
15- 3- 2	Describing resultant changes in vertical distance of two objects in same time if one is given horizontal velocity
16- 1- 1	Describing vector sum of forces to be zero
16-11- 4	Verifying sentence model, $\frac{a}{F}=K$
16-13- 6	Verifying sentence model, $aM=K$

17-10- 2	Verifying sentence models, $F=\frac{Mv^2}{r}$ and $F=Mw^2r$
18- 1- 1	Choosing titles for graph models
18-10- 3	Describing acceleration of object in simple harmonic motion as it passes through equilibrium point
18-14- 5	Describing velocity of object in simple harmonic motion
18-22- 9	Verifying sentence model, $f_f-f_s=f_b$, for beat of simple harmonic motion
19- 3- 2	Verifying sentence model, $V=V_m \cos\theta$, for simple harmonic motion
20- 3- 2	Describing the spring constant
20-11- 8	Describing the frequency of simple harmonic motion from Lissajous figures
21- 8- 5	Verifying developed sentence model for equating the momentum of two objects when the force acting on each is equal and opposite
22- 8- 3	Describing energy lost by system as energy changed to heat energy
22-12- 5	Describing interpretation of weighted disc on an inclined plane using an energy approach
24- 5- 1	Describing buoyant force acting on a metal block from measuring weight of water it displaces
25-11- 1	Describing determined water equivalent of a calorimeter
25-13- 2	Describing equivalence of calories and joules from volts, amps, and change in water temperature
25-18- 5	Describing heat of fusion of water
25-21- 6	Describing heat of vaporization of water
26- 4- 3	Describing horsepower one can develop in running up a flight of stairs
28-12- 4	Verifying a model, $PE=\frac{1}{2}Kx^2$, by shooting a tape of a spring with mass attached
28-17- 6	Describing the speed of sound in a closed tube by using resonance

29- 5- 2	Describing relationship between the amount a spring is stretched and the velocity of a wave
29- 6- 3	Describing relationship between the mass of the magnets on a magnet board and the velocity of a wave
30-10- 8	Describing relationship between impedance and wave velocity
30-12- 9	Describing evidence on which interpretation of data is based
30-13-14	Describing cause of observed effect of glass object not being visible in a liquid that has the same impedance to light rays as glass
31- 7- 5	Describing the effect of the depth of the water on the apparent elevation of an object submerged in it
31-21-12	Describing the relationship between wave length and velocity of light waves in glass
32- 3- 2	Describing the cause of circular spectrum in terms of spherical aberration
32-16- 9	Describing a convex air lens in glass as a diverging lens
32-19-14	Verifying that the image model, $\frac{1}{f}=\frac{1}{d_o}+\frac{1}{d_i}$, of a converging lens holds for a converging mirror
34- 1- 1 - 2	Describing qualitatively the relationship between the amplitude and phase of combining wave pulses and the amplitude of the resulting pulse
34-36-30	Describing relationship between the distance between glass plates the the wave length of micro waves for destructive interference and for constructive reinforcement
35-20-12	Describing direction blue sky light is polarized
37-10- 1	Describing evidence that indicates that $\frac{Fd^2}{q_1 q_2}$ remains constant
37-12- 3	Describing charge on ping pong balls in stat-coulombs from data collected

PREDICTING

Data Table Model

2- 9- 1	Applying rules of interpolation and extrapolation to data table model data to formulate predictions
29-17- 8	Describing distance of earthquake from receiving station by being given velocities of longitudinal and transverse waves and their difference in arrival time

PREDICTING

Graph Model

2-12- 3	Applying rules of interpolation to graph model data to formulate predictions
3-19-13	Constructing graph to predict an event in time and space
4- 7- 5	Constructing test of prediction formulated
5-10- 7	Constructing a graph model to predict positions in time and space for successive occurances of a cyclic phenomena
6- 4- 2	Constructing graph model based on frame of refererce to predict an event in time
6- 7- 4	Constructing graph model based on frame of reference to predict direction and distance at which an event will take place
9- 7- 6	Making and testing prediction of what inverse variation plot of data will look like

PREDICTING

Sentence Model

4- 7- 5 Constructing a sentence model of distance, velocity, and time to predict an event in time and space

4- 7- 5 Constructing test of prediction formulated

5-10- 7 Constructing a sentence model to predict positions in time and space for successive occurrences of a cyclic phenomena

6- 8- 5 Constructing sentence model based on frame of reference to predict direction and distance at which an event will take place

7-23- 8 Applying rules for operations with dimensions to predict dimensions of unknown

21- 8- 5 Constructing a sentence model to predict the relationship between the mass of each of two objects and the resulting velocity when an equal force acts on each

37-11- 2 Applying the formula, $F=\frac{q_1 q_2}{d^2}$, to predict the force in dynes when the charges are given in stat-coulombs and the distance in centimeters

PREDICTING

Diagram Model

6-10- 6	Constructing predictions based on frame of reference
8- 3- 1	Constructing scale drawing of vectors to predict unknown distance and direction
8- 8- 2	Applying trigonometric functions to predict vector displacement
9- 6- 3	Constructing relationship between pulley diameters and speed of belt to predict inverse variation of diameter to speed of revolution
9- 6- 4	Constructing test of prediction formulated
11-14- 5	Constructing prediction of Ideal Mechanical Advantage of a pulley system
11-17- 7	Constructing relationships of inclined plane to predict Ideal Mechanical Advantage
11-22- 9	Constructing relationships of compound machine, inclined plane and wheel and axle, to predict Ideal Mechanical Advantage
12- 3- 1	Constructing prediction of distance a ball will travel on inclined plane during tenth second from series of distances given for the first four seconds
20- 2- 1	Constructing prediction of relative period or frequency of different masses on springs with the same spring constant
22- 7- 2	Describing a predicted series of events for a balanced pulley system when one is accelerated by a force of 10 grams
22-24-13	Describing predicted potential energy loss of a pendulum in gram centimeters if it has a mass of 100 grams and falls a vertical distance of 10 cm
24-12- 5	Describing predicted water line of a 1000 cm^3 block of wood that weighs 700 grams
29-16- 7	Describing where earthquake took place by noting where arcs drawn from three receiving stations intersected

30- 7- 1	Constructing diagrams of standing waves on the Bell Wave Machine for reflection at a free end and at a clamped end
30- 8- 2 3	Describing impedance prediction as waves travel from short arm to long arm and long arm to short arm Bell Wave Machine
32-18-13	Describing predicted effect of a converging mirror on the size of the image
33-22- 6	Describing predicted relationship between the diameters of a circle of light from a point source and the reading of a foot candle meter

PREDICTING

Descriptive Model

9-17-13 Applying variation process to predict the weight of a paper disc by having weighed one of a different diameter

9-14-13 Testing prediction by weighing disc

29-10- 4 Describing hypothetical problems for a concert in a large auditorium if the velocity of sound depended on wave length and amplitude

32-17-10 Constructing a prediction of index of refraction when light travels from water to glass by being given the index of refraction when light travels from air to water and air to glass

35- 8- 6 Describing and checking prediction of VTVM reading for polarizing lens axis angles of 60°, 30°, and 45° based on assumption that the amount of light varies as the cosine of the angle between the polarizing and analyzing lenses

35-13- 9 Describing prediction of direction of polarization of reflected waves and of transmitted waves

PREDICTING

Inquiry

3-17-12 Applying rules of interpolation to data collected experimentally to formulate predictions

3-17-12 Constructing test of prediction formulated

10- 9- 6 Constructing relationship between unknown weight and two known weights of pulley system with friction that result in balance forces with zero acceleration to predict unknown weight

11- 1- 1 Construct relationships of moments of force to predict weight of object that produces zero acceleration of frictionless pulley system

15- 2- 1 Construct prediction of free fall time relationship of two objects dropped from same height if one is given horizontal velocity

22- 9- 4 Describing prediction of how high a 20 gram mass would move if a 10 gram mass force acts through 20 cm on a pulley system

23-24- 9 Describing predicted frequency setting of audio generator by producing standing waves and measuring their wave length

2[illegible]- 5- 3 Describing predicted effect on wave motion of adding mass to magnets on magnet board from student developed model

31-15- 9 Describing predicted critical angle for glass air boundary from determined index of refraction for the glass block

32-16- 9 Describing prediction of whether a double convex air lens in glass will be a diverging or converging lens

33- 4- 2 Describing predicted gamma ray count with two shields based on the two used separately

34- 2- 3 Describing predicted amplitude for combined pulses of the same amplitude if they were in phase when they met and if they were 180° out of phase when they met

34-36-30 Describing and checking predicted relationship between the distance between glass plates and the wave length of micro waves for destructive interference and constructive reinforcement

37-13- 6 Describe predicted motor disc turns of a kilowatt hour meter for 50 watts and 300 watts from measured revolutions for 100 watts and 200 watts

CONTROLLING VARIABLES

Data Table Model

2- 9- 1 Identifying that the distance an object travels varies with time of travel if the velocity remains constant

2-11- 2 Describing paired quantities that vary as number pairs

3-17-11 Describing variable distances

CONTROLLING VARIABLES

Graph Model

2-11- 2	Identifying paired quantities that vary as number pairs
3- 4- 1	Describing the slope of a graph line as the rate at which space and time vary
3- 4- 1	Describing a line parallel to the axis of a graph as representing only one quantity that is varying
3- 4- 1	Describing straight line plot as representing a constant of variation
3- 7- 2	Describing a constant of variation by constructing a straight line plot on a graph
3-23-16	Ordering a variable speed to cause a simultaneous occurrence in time and space
3-25-17	Describing a constant change in distance per time as acceleration
3-25-17	Describing cause of sudden variance in distance per time
4- 7- 5	Describing how velocities varied by constructing two line plots on a space and time graph model
6- 4- 2	Describing velocity variables in a chosen frame of reference
9- 7- 7	Constructing graph plot of inverse variation
9- 8- 9	Constructing graph plot of inverse variation using reciprocal of one factor
9- 8- 9	Constructing graph plot of inverse variation using logarithm method
9-11-10	Describing a constant of variation

CONTROLLING VARIABLES

Sentence Model

4- 7- 5 Describing general relationship of variables by developing a sentence model for distance and velocity there time is constant

4-16-11 Describing how the sides of right triangles vary by using trigonometric functions

4-17-12 Describing how the sides of right triangles vary by using the pythagorean theorem

6- 4- 2 Describing velocity variables in a chosen frame of reference

9- 6- 4 Identifying inverse variation

CONTROLLING VARIABLES

Diagram Model

9- 6- 3 Identifying inverse variation

12- 3- 1 Describing regular variation of distance per time for a constant accelerating body

CONTROLLING VARIABLES

Descriptive Model

CONTROLLING VARIABLES

Inquiry

3-19-13	Manipulating variable of time to cause a simultaneous occurrence in time and space
3-22-14	Manipulating variable of distance to cause a simultaneous occurrence in time and space
3-22-15	Manipulating variables of time and distance to cause a simultaneous occurrence in time and space
10-11- 7	Manipulating variables of distance and weight to equalize moments of force
16-11- 4	Ordering constant mass in investigating F=Ma
27-18- 7	Describing effect of the mass of a wire on the resonant frequency by varying the diameter of wire made of same material
29- 5- 2	Describing effect of stretching a spring on the time it takes a wave to travel two lengths of the spring
29- 5- 2	Describing effect of stretching a spring on wave velocity
29- 6- 3	Describing the relationship between the mass of each element and the velocity of the wave as a usable model (doubling mass on arms of magnet board)
31- 7- 5	Describing the effect of the depth of water to the apparent elevation of an object at the bottom
33- 4- 3	Describing the effect of the thickness of polyethylene discs on scalar count of Gamma ray energy (reflection kept constant by using single discs of same substance that vary in thickness)
35- 2- 2	Describing effect of polarizing grid on electromagnetic waves by observing effect of rotating disc through ninety degrees between transmitter and receiver
35- 3- 3	Describing effect of polaroid lenses on transmitted light by using one lens as a polarizer and second as analyzer

37-10- 1 Manipulating the static charge on ping pong balls to demonstrate that $\frac{Fd^2}{q_1 q_2}$ remained constant

DEFINING OPERATIONALLY

Data Table Model

DEFINING OPERATIONALLY

Graph Model

3- 4- 1 Describing relative speed as greater slope of space-time plot

3-10- 4 Describing a graph line with zero slope as representing zero speed

DEFINING OPERATIONALLY

Sentence Model

21- 2- 1 Describing impulse and momentum dimensions based on force units of the dyne, newton, and poundal

21- 3- 2 Describing impulse and momentum dimensions based on the absolute mass dimensions of slugs

21- 8- 5 Describing an event where forces are equal and opposite by equating the momentum of two masses

22- 6- 1 Describing dimensions of an erg from force dimensions of a dyne

DEFINING OPERATIONALLY

Diagram Model

33-22- 6	Describing decreased light intensity on the basis of increased area being lighted
34- 7-10	Describing reinforcement and interference at given points in terms of wave length differences
34-14-15	Describing a wave front line as first order

DEFINING OPERATIONALLY

Descriptive Model

21- 9- 6 Describing what ΔV_W represents when referring to the oar and water situation when a boat is veing rowed

34-12-14 Describing the diameter of a wire in sodium flame wave lengths

DEFINING OPERATIONALLY

Inquiry

5- 3- 3 Constructing operational definition of a radian

16-15- 7 Constructing operational definition of force with dimension of $\frac{\text{lb ft}}{\text{Sec}^2}$

22- 8- 3 Describing a procedure to measure energy changed to heat energy on each impact

24- 5- 1 Describing buoyant force acting on a metal block submerged in water

24- 7- 2 Describing pressure acting on a metal block submerged in water

28-17- 6 Describing speed of sound waves by using resonance of a closed tube

28-19- 7 Describing speed of sound waves in free space

28-21- 8 Describing speed of sound waves in metal

30-12- 9 Describing infinite impedance as when no wave energy is transmitted

34-19-17 Describing continuous spectrum of color and their sequence using the grating theory

FORMULATING HYPOTHESES

Data Table Model

FORMULATING HYPOTHESES

Graph Model

3-26-17 Constructing hypothesis concerning cause of changing slope of line on graph model

4- 7- 5 Constructing hypothesis of space and time relationship by developing graph model

9- 7- 6 Constructing hypothesis of nature of graph line for an inverse variation

FORMULATING HYPOTHESES

Sentence Model

4- 7- 5	Constructing hypothesis of space and time relationship by developing sentence model
9-14-12	Constructing hypothesis of variation relationships to formulate prediction
12- 4- 3	Constructing hypothesis in sentence model form for the series of distance numbers for any value of acceleration
15-21-12	Constructing hypothesis of projection angle for maximum flight time
15-22-13	Constructing hypothesis of projection angle for maximum range of projectile
18-21- 8	Constructing hypothesis of general sentence model for frequency of beat of simple harmonic motion
19-11- 6	Constructing hypothesis of sentence model for the acceleration of simple harmonic motion for any phase angle

FORMULATING HYPOTHESES

Diagram Model

5- 7- 6	Constructing hypothesis of relationship between drive pulley size, speed of rotation, belt speed, and driven pulley speed
6-10- 6	Constructing hypothesis of frame of reference cause and effect
12- 3- 1	Constructing hypothesis of regular series of numbers for distance per time interval for a uniformly accelerating object
20- 2- 1	Constructing hypothesis of relative period or frequency of simple harmonic motion
30-17-17	Constructing hypothesis to explain the double image of a flame on an unlighted candle behind a pane of glass when a lighted candle is on the same side of the glass plate as the observer

FORMULATING HYPOTHESES

Descriptive Model

12- 4- 3	Constructing hypothesis in descriptive model form for the series of distance numbers for any value of acceleration
21- 4- 3	Constructing hypothesis about force and time to explain how one catches a baseball to prevent the sting
30-13-13	Constructing hypothesis to explain why a window pane acts as a mirror if one is in a lighted room and it is dark outside
30-14-15	Elaborating on the hypothesis that the rumble of thunder is due to successive reflections of the sound
31- 6- 4	Construct hypothesis to explain why sun can be seen before sunrise and after sunset
32-17-11	Constructing hypothesis of why objects are out of focus when eye is in contact with water and in focus when a swim mask is used to view objects under water
34-30-23	Constructing hypothesis to explain production of colors based on five data statements
34-32-25	Constructing hypothesis to explain why waves reflected from a glass surface do not change phase upon reflection

FORMULATING HYPOTHESES

Inquiry ________

5- 3- 3	Constructing hypothesis of the number of degrees in a radian
5-10- 7	Constructing hypothesis of cyclic phenomena in time and space
9- 4- 1	Constructing hypothesis that velocity and time are inversely proportional if distance remains constant
10-11- 7	Constructing hypothesis of conditions for zero acceleration in a situation dealing with moments of force
10-11- 7	Constructing hypothesis concerning error
11- 1- 1	Constructing hypothesis of ratio of speed of weights on two different sized wheels on same axle
11- 9- 2	Constructing hypothesis of conditions under which resistance would move down with zero acceleration if effort force were zero
11-14- 5	Constructing hypothesis of relationship between the number of ropes supporting the resistance and the Ideal Mechanical Advantage of the system
11-22- 9	Constructing hypothesis of Ideal Mechanical Advantage of a compound machine
15- 3- 2	Constructing hypothesis that horizontal velocity does not effect acceleration due to gravity
30-10- 8	Constructing hypothesis of relationship between impedance and wave velocity
30-13-14	Constructing hypothesis to explain why a glass tube is not visible below the surface of a liquid that has the same impedance to light waves as glass has
32-17-12	Constructing hypothesis to explain why the hot air from a bunsen burner flame produces an image on a screen when light is shone through it
34- 7-10	Constructing hypothesis in terms of wave length differences to explain reinforcement and interference

35-20-13 Constructing hypothesis to explain why sunset is red from data collected from colloidal sulphur experiment

FORMULATING MODELS

Data Table Model

2- 9- 1 Identifying a data table model

2-11- 2 Recording data on a data table model

33-11- 7 Constructing and recording data on a data table model

FORMULATING MODELS

Graph Model

2-11- 2	Identifying a coordinate axis graph model
2-11- 2	Distinguishing plotted number pairs
3- 7- 2	Constructing a line on a graph model to represent average speed
3- 9- 3	Constructing lines on graph model based on a descriptive model
3-12- 7	Constructing a space and time graph in fourth quadrant to represent negative distance
3-17-12	Constructing a space and time graph to make interpolated predictions
3-19-13	Constructing a space and time graph to predict an event in space and time
6- 4- 2	Constructing a frame of reference space and time graph to make prediction
7- 4- 1	Constructing a one dimensional space model
7- 5- 2	Constructing and plotting points on polar coordinates
7-11- 5	Constructing a three dimensional graph model
9- 7- 7	Constructing a graph of an inverse variation
9- 7- 8	Constructing a graph of an inverse variation where one quantity is reciprocated
9- 8- 9	Constructing a graph of inverse variation using logarithm method
15- 7- 4	Constructing a shadow graph of an object that has horizontal velocity and accelerates freely due to the force of gravity
19-20- 8	Producing a graph of the motion of a tuning fork on an oscilloscope
20-14-10	Constructing a graph of Lissajous figures

22-21- 8	Describing how the area for heat energy of the total energy put into the pulley system was drawn
23- 4- 2	Constructing a spark tape record of a falling plumet
27- 8- 1	Construct a resonance curve for mechanical resonance from measured natural and forced frequencies and steady state amplitude

FORMULATING MODELS

Sentence Model

4- 2- 1	Describing the code of sentence model by referring to a diagram model
4- 5- 3	Transforming sentence models
4- 7- 5	Constructing a distance, velocity, and time sentence model to solve a chase problem
5- 2- 1	Verifying validity of a sentence model
6- 4- 2	Constructing a frame of reference space and time sentence model to make prediction
12- 4- 3	Constructing a sentence model for the series of distance numbers for any value of acceleration
13- 2- 1	Constructing analogous rotational motion sentence models from translational motion sentence models
18-21- 8	Constructing a general sentence model for the frequency of the beat of simple harmonic motion
21- 8- 5	Constructing a sentence model to describe the relationship between the masses and the velocities when the force acting on each is equal ($M_A V_A = M_B V_B$)
21-21- 9	Developing a sentence model for the resonant or natural frequency of a wire from given dimensions of factors involved

FORMULATING MODELS

Diagram Model

4- 2- 1	Identifying a diagram model
4- 2- 1	Describing symolic code of a diagram model
4-16-11	Describing angles of a right triangle using trigonometric functions
4-17-12	Describing relationship of sides of a right triangle by applying the pythagorean theorem
8- 3- 1	Constructing a scale drawing of vector quantities
8-11- 3	Constructing vector components
20-11- 8	Producing Lissajous figures
22-23-12	Constructing a compound machine to scale to demonstrate that the center of gravity of the cart and bucket remains at the same level in the gravity force field as the cart moves up the inclined plane and the bucket moves down
28- 7- 1	Describing degree and radian designations on a wave diagram
30- 7- 1	Constructing a diagram of phase change predictions at a free end and at a clamped end of the Bell Wave Machine
32- 8- 4	Constructing a wave front model for flat wave fronts passing through and leaving a double concave lens

FORMULATING MODELS

Descriptive Model

3-22-14 Presenting a report of a project

12- 4- 3 Constructing a descriptive model for the series of distance numbers for any value of acceleration

35-23-14 Describing organization of a presentation one would use to explain polarization to a person unfamiliar with this phenomena

FORMULATING MODELS

Inquiry

5- 3- 3 Constructing and measuring degrees in a radian and radians in a circle

29- 6- 3 Constructing and testing a sentence model of the relationship between the mass of the element on a magnet board and the velocity of waves

34-11-13 Constructing observed curved wave fronts to complete a diagram that have been observed as straight line waves pass through openings between paraffin blocks in wave tank

EXPERIMENTING

Data Table Model

EXPERIMENTING

Graph Model

3-17-12	Verifying interpolated distance predictions made from space/time graphed data
3-19-13	Verifying space and time predictions based on theoretical space/time graph with object traveling same distance in different times
3-22-14	Verifying space and time predictions based on theoretical space/time graph with objects traveling different distances in same time
3-22-15	Verifying space and time predictions based on theoretical space/time graph with objects traveling different distances in different amounts of time
4- 7- 5	Verifying the validity of a distance, velocity, time graph model developed by student
6- 4- 2	Verifying frame of reference graph model for distance, velocity, and time

EXPERIMENTING

Sentence Model

4- 7- 5 Verifying the validity of a distance, velocity, time sentence model developed by student

5- 2- 1 Verifying sentence model, $V=2\pi rw$

6- 3- 1 Verifying frame of reference sentence model for distance, velocity, and time

9- 4- 1 Determining the constant of variation for the sentence model, $D=Vt$, by measuring the time it took objects to go a given distance at varying rates

9- 6- 3 Verifying prediction of an inverse variation for the sentence model, $K=rw$

12-11- 7 Checking the sentence model, $a=\frac{2s}{t^2}$, and also determining the value of the acceleration for a given weight attached to string wound around wheel and axle

12-11- 7 Checking the sentence models, $V=at$ and $V=2aS$

12-16-10 Checking the sentence model, $S=V_0t + \frac{1}{2}at^2$

12-20-12 Applying the sentence model, $S=V_0t - \frac{1}{2}at^2$

13- 4- 3
      - 4 Applying the sentence models; $W=2\theta$, $\theta=w_0t + \frac{1}{2}t^2$, and $\theta=w_0t - \frac{1}{2}t^2$

15- 7- 4 Verifying sentence model, $-y=Kx^2$, by shadow graphing path of object

16- 5- 2 Verifying validity of sentence model, $a=K\frac{F}{M}$

17-10- 2 Verifying validity of sentence model, $F=\frac{MV^2}{r}$

18-22- 9 Verifying validity of sentence model, $f_f-f_s=f_b$, for frequency of beat of simple harmonic motion

19- 3- 2 Checking the sentence model, $V=V_m\cos\theta$, for the velocity of simple harmonic motion

19- 8- 5	Checking the sentence model, $a=a_m\text{sine}\theta$, for acceleration of simple harmonic motion
21- 8- 5	Developing and checking a sentence model for equating the momentum of two masses when the force acting on each is the same
23- 4- 2	Testing the equivalence of loss of potential energy and gain of kinetic energy by comparing calculated and measured values of V and h for a falling plumet using a spark tape record
28-12- 4	Checking experimentally the model, $PE=\frac{1}{2}Kx^2$, using a mass on a spring and a spark tape recorder

EXPERIMENTING

Diagram Model

6-10- 6 Verifying frame of reference predictions based on dimensions of rollers judged to be pertinent

EXPERIMENTING

Descriptive Model

EXPERIMENTING

Inquiry

3-17-11 Determining distances objects traveling at different rates move during one minute

9-14-13 Collecting data on a paper disc to predict weight of another disc using the process of variation

10- 3- 4 Determining balanced forces for a frictionless pulley system utilizing static and dynamic balance (zero acceleration)

10- 8- 5 Determining the force of friction in a pulley utilizing dynamic balance

10- 9- 6 Determining the weight of an object utilizing pulley with friction and dynamic balance

10-11- 7 Verifying prediction of balanced moments of force

10-13- 4 Checking Ideal Mechanical Advantage and determining Actual Mechanical Advantage and actual mechanical advantage of a four rope pulley system

11-16- 6 Designing and analyzing a pulley system

11-20- 8 Checking Ideal Mechanical Advantage and determining Actual Mechanical Advantage and actual mechanical advantage of an inclined plane

11-22- 9 Investigating relationship of Ideal Mechanical Advantage of inclined plane to Ideal Mechanical Advantage of wheel and axle when they are combined to form a compound machine

14- 8- 1 Determining the acceleration of gravity

20- 3- 2 Verifying prediction of period of a spring with weight attached

20- 8- 7 Checking prediction of a pendulum that would have a period of one second

24- 5- 1 Designing and carrying out an experimental study of the buoyant force acting on a metal block submerged in water

30-22-19 Demonstrating experimentally with a given set up that the angle of incidence is equal to the angle of reflection

32-16- 9	Investigating the optical properties of a double convex air lens in glass
33- 4- 3	Investigating the absorption of gamma rays in relationship to the thickness of polyethylene discs
34-36-30	Determining the relationship between the distance between glass plates and the wave length of micro waves for destructive interference and constructive reinforcement
35- 1- 1 - 2	Investigating the wave orientation of electro magnet waves using a rotating dipole antenna and polarizing grids
35- 3- 3	Designing and carrying out an experiment to determine if a polarizing grid reflects electro magnetic waves
37-18- 6	Investigating the relationship of the revolutions of the motor disc of a kilowatt hour meter per time to the wattage of a bulb being used

APPENDIX C

CHARACTERISTICS FORM SAMPLE

SAMPLE CHARACTERISTICS

Student					ITED Standard Score			
Number	Name	Sex	Class	IQ	Sci Bkgrd	Sci Rdg	Math	Comp

APPENDIX D

ACHIEVEMENT REPORT FORM

[illegible] -- Columbus

Student		Part																																					
Name	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18	19	II	20	21	22	23	24	25	26	27	28	III	29	30	31	32	33	34	35	36	37	IV	

SELECTED REFERENCES

SELECTED REFERENCES

PUBLIC DOCUMENTS

Defense Document Center
1966 Thesaurus of D.D.C. descriptors. Alexandria: Cameron Station.

Iowa Department of Public Instruction
1965 Data on Iowa schools. Des Moines, State of Iowa (mimeographed).

Iowa Department of Public Instruction
1970 Data on Iowa schools, school year 1969-1970, part 1, pupils. Des Moines, Iowa (mimeographed).

Iowa Department of Public Instruction
1970 Data on Iowa schools, school year 1969-1970, part 3, educational programs. Des Moines, Iowa (mimeographed).

Simon, K. A., and W. V. Grant
1970 Digest of educational statistics. Washington, D. C., U. S. Government Printing Office.

BOOKS

Berlyne, D. E.
1960 Conflict, arousal, and curiosity. New York, McGraw-Hill.

Bloom, B. S., ed.
1956 Taxonomy of educational objectives, handbook I: cognitive domain. New York, David McKay Company.

Bourne, L. E., Jr.
1966 Human conceptual behavior. Boston, Massachusetts, Allyn and Bacon, Inc.

Bruner, J. S., J.J. Goodnow, and G. A. Austin
1956 A study of thinking. New York, John Wiley & Sons, Inc.

Bruner, J. S., J. J. Goodnow, and G. A. Austin
1967 A study of thinking. New York, John Wiley & Sons, Inc.

Buros, Oscar K., ed.
1959 The fifth mental measurement yearbook. Highland Park, New Jersey, The Gryphon Press.

Downie, N. M. and R. W. Heath
1965 Basic statistical methods. New York, Harper and Row.

deCharms, R. and V. Carpenter
1968 Research and development toward the improvement of education. Edited by H. J. Klausmeier and G. T. O'Hearn. Madison, Dembar Educational Research Services, Inc.

deCharms, R., K. Dougherty, and S. Wurtz
1965 The origin-pawn variable. Unpublished manuscript, Washington University (referred to in deCharms and Carpenter).

Fowler, H.
1965 Curiosity and exploratory behavior. New York, Macmillan & Co.

Gagne, R. M.
1965 The conditions of learning. New York, Holt, Rinehart and Winston, Inc.

Glaser, Robert
1968 Learning. Learning Research and Development Center, University of Pittsburg. (Ed 019 140).

Guilford, J. P.
1968 Intelligence, creativity and their educational implications. San Diego, Robert R. Knapp.

Hall, J. F.
1971 Verbal learning and retention. New York, J. B. Lippincott Co.

Nedelsky, L.
1965 Science teaching and testing. New York, Harcourt, Brace, and World, Inc.

Shaftel, F. R., C. A. Crabtree, and Rushworth
1960 The problems approach and the social studies. Curriculum series No. 9. Edited by R. E. Gross, R. H. Muessig and G. L. Fersh. Washington, D. C., National Council for the Social Studies.

Skinner, G. F.
1953 Science and human behavior. New York Macmillan & Co.

Turabian, K. L.
1967 A manual for writers of term papers, theses, and dissertations. Chicago, University of Chicago Press.

PERIODICALS AND JOURNALS

AAAS Commission on Science Education
1966 The process method of teaching science. Grade Teacher 83:60-61.

Ashenfelter, J. W.
1969 A partial learner-paced approach to teaching PSSC physics. The Physics Teacher 7:93-8.

Bracht, G. H.
1970 Experimental factors related to aptitude-treatment interactions. Review of Educational Research 40:627-45.

Cogan, M. S.
1958 The behavior of teachers and the productive behavior of their pupils. Journal of Experimental Education 27:89-124.

Fowler, W.
1965 A study of process and method in three-year-old twins and triplets learning to read. Genetic Psychology Monograph 72:3-89.

Gagne, R. M.
1962 The acquisition of knowledge. Psychological Review 4:355-65.

Gagne, R. M.
1967 Curriculum research and the promotion of learning. AERA Monograph Series on Curriculum Evaluation. Chicago, Rand McNally and Company 1:19-38.

Gagne, R. M. and N. E. Paradise
1961 Abilities and learning sets in knowledge acquisition. Psychological Monographs 75, No. 14 (whole No. 518).

Gagne, R. M., et.al.
1962 Factors in acquiring knowledge of a mathematical task. Psychological Monographs 76, No. 7 (whole No. 526).

Glaser R., and L. B. Resnick
1972 Instructional psychology. Learning Research and Development Center, University of Pittsburgh. Reprinted from Annual Review of Psychology, Vol. 23.

Heath, R. W. and D. W. Stickell
1963 CHEM and CBA effects on achievement in chemistry. Science Teacher 30:45-46.

Hipsher, W. L.
1961 Study of high school physics achievement. Science Teacher 28:36-37.

Hull, C. L.
1930 Knowledge and purpose as habit mechanisms. Psychology Review 57:511-525.

Humphreys, L. G.
1960 Some investigations of the simplex. Psychometrika 25:313-23.

Kendler, T. S.
1960 Learning development and thinking. Fundamentals of psychology: the psychology of thinking. Edited by E. Harms. Annual of New York Academy of Science 91:56-60.

Koser, J. F.
1969 Independent scheduling enhances IPS program. Science Teacher 36:74-76.

Lefler, R. W.
1953 Trends in high school physics. The Bulletin of the National Association of Secondary School Principals--Science in Secondary Schools Today 37:74-83.

Marie, E., Sister
1961 A comparison of inductive and deductive methods of teaching high school chemistry. Science Education 45:436-43.

McBurnery, W. F.
1969 Individualized instruction: a case for the independent student investigation in science. School Science and Mathematics 69:827-30.

Merrill, M. D.
1965 Correction and review of successive parts in learning a hierarchial task. Journal of Educational Psychology 56:225-234.

Moore, A. J.
1968 Harvard project physics--a cogent approach. Science Education 52:337-45.

Osler, S. F. and M. W. Fivel
1961 Concept attainment: I. The role of age and intelligence in concept attainment by induction. Journal of Experimental Psychology 62:1-8.

Osler, S. F. and G. E. Troutman
1961 Concept attainment: II. Effect of stimulus complexity upon concept attainment at two levels of intelligence. Journal of Experimental Psychology 62:9-13.

Ramsey, I. L. and S. L. Wiandt
1967 Individualizing elementary school science. School Science and Mathematics 67:419-27.

Reed, H. Q.
1962 Implications for science education of a teacher competence research. Science Education 44:473-86.

Resnick, L. B., A. W. Siegel and I. Kresh
1971 Transfer and sequence in learning double classification skills. Journal of Experimental Child Psychology 11:139-49.

Richard, P. W.
1969 Experimental individualized BSCS biology. Science Teacher 36:53-54.

Walberg, H. J.
1969 A model for research on instruction. School Review 78:185-200.

Walbesser, H. H., Jr.
1966 Science curriculum evaluation: observations on a position. The Science Teacher 33:34-39.

Watson, F. G.
1967 Why do we need more physics courses? Physics Teacher 5:212-14.

Welch, W. W.
1967 High school physics enrollments. Physics Today 20:9-13.

Welch, W. W.
1968 The need for evaluating national curriculum projects. Phi Delta Kappan 49:530-533.

Welch, W. W.
1968 The impact of national curriculum projects--the need for accurate assessment. School Science and Mathematics 68:225-34.

Welch, W. W.
1968 Curriculum decisions--how can evaluation assist science teachers. Science Teacher 35:22-25.

Welch, W. W.
1969 Some characteristics of high school physics students: circa 1968. Journal of Research in Science Teaching 3:242-247.

Welch W. W.
1969 Correlates of course satisfaction in high school physics. Journal of Research in Science Teaching 6:54-58.

Welch, W. W. and R. G. Bridgham
1968 Physics achievement gains as a function of teaching duration. School Science and Mathematics 47:449-454.

Welch, W. W. and M. O. Pella
1968 The development of an instrument for inventorying knowledge of the process of science. Journal of Research in Science Teaching 5:64-68.

Welch, W. W. and H. J. Walberg
1968 A design for curriculum evaluation. Science Education 52:10-15.

Woodrow, H. A.
1946 The ability to learn. Psychological Review 53:147-58.

PAPERS AND REPORTS

Ahlgren, A.
1969 Reliability, predictive validity and personality bias of confidence--weighted scores. Paper presented to the American Educational Research Association. Cambridge, Harvard University.

Ahlgren, A.
1969 Evaluation of harvard project physics course interim report. Paper presented to American Association of Physics Teachers. Cambridge, Harvard University.

American Institute of Physics
1960 Physics in your high school. New York, McGraw-Hill.

Babcock, C. C.
1967 The urgency for individualized instruction. Paper presented at the Northwest Drive-In Conference on Administrative Leadership Spokane.

Burkman, E.
1971 Intermediate science curriculum study, part a, final report. Florida State University, Tallahassee.

Burkman, E.
1971a Intermediate science curriculum study, part b, final report. Florida State University, Tallahassee.

Champagne, A. B.
1970 IPI science today. Paper presented at Annual Meeting of the National Science Teachers Association. Cincinnati.

Finsand, D. L. and A. Potter
1968 The scope of S.C.O.P.E.S.: concepts, generalizations, conceptual schemes, and processes. Cedar Falls, University of Northern Iowa.

Gagne, R. M.
1965 The psychological bases of science--a process approach. The American Association for the Advancement of Science. AAAD Miscellaneous Publication 65-8.

Harvard Project Physics
1969 Newsletter 9. Cambridge, Harvard University.

Heathers, G.
1971 A definition of individualized instruction. Paper Presented to AERA Annual Meeting, New York.

Rutherford, J.
1969 A curriculum development project director evaluates curriculum evaluation. Paper presented at a joint meeting of the National Association for Research in Science Teaching and the American Education Research Association. Cambridge, Harvard University.

Sears, P. S. and E. R. Hilgard, ed.
1964 Theories of learning and instruction. The sixty-third yearbook of the national society for the study of education-part I. Chicago, University of Chicago Press.

Simmons, J. C. and R. J. Garvue
1969 An examination of the socio-economic implications of the adoption of the individually prescribed instructional systems by school systems. U. S. Department of Health, Education and Welfare: Office of Education, Department of Research.

Szabo, M. and J. F. Feldhusen
1970 The relationship of intellective, personality, and biographical variables to success in an independent study science course at the college level. Paper presented at the National Convention of the American Educational Research Association, Minneapolis.

Walbesser, H. H., Jr.
1965 An evaluation model and its application. The American Association for the Advancement of Science. AAAS Miscellaneous Publication 65-9.

Walbesser, H. H., Jr.
1968 An evaluation model and its application, Second report. The American Association for the Advancement of Science. AAAS Miscellaneous Publication 68-4.

Wallace, W.
1963 The BSCS 1961-62 evaluation program--a statistical report. BSCS Newsletter 19:22-24.

Watson, F. G.
1969 Educational implications of evaluation in a national curriculum project. Paper presented to the American Educational Research Association. Cambridge, Harvard University.

Welch, W. W.
1968 The role of evaluation in the development of harvard project physics. Cambridge, Harvard University.

Welch, W. W.
1969 Applied research in a curriculum project: accomplishments and limitations. Paper presented to the American Educational Research Association. Cambridge, Harvard University.

THESES

Kuperman, A.
1966 Relations between differential constraints, affect, and the "origin-pawn" variable. Unpublished doctoral dissertation, Washington University.

Tamppari, R. P.
1969 A model for determining biological concept attainment. Doctoral Theses, Michigan University, Ann Arbor.

Tweeten, P. W.
1968 Correlative relationships between student achievement and selected evaluative measures of high school programs. Doctoral Theses, University of Iowa, Iowa City.

TESTS AND INSTRUMENTS

Lindquist, E. R., et.al.
1960 The Iowa tests of educational development. Chicago, Science Research Associates, Inc.

Myers, I. B.
1962 Myers-Briggs type indicator (F). Princeton, Educational Testing Service.

Physical Science Study Committee
1964 Final examination--form F. Princeton, Educational Testing Service.

The University of Iowa
1971 How to use the test results of the Iowa tests of educational development. A manual for teachers and counselors. Iowa City, The University of Iowa.